Astronomisches Institut 2014: Aktivitäten und Projekte

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Astronomisches Institut

Aktivitäten der Forschungsgruppe Satellitengeodäsie am AIUB

R. Dach
D. Arnold, ~~C. Baumann~~, S. Bertone,
~~H. Bock~~, Y. Jean, ~~S. Lutz~~,
U. Meyer, E. Orliac,
L. Prange , S. Schaer, K. Sosnica,
P. Walser

Astronomisches Institut

Updating the CODE rapid product

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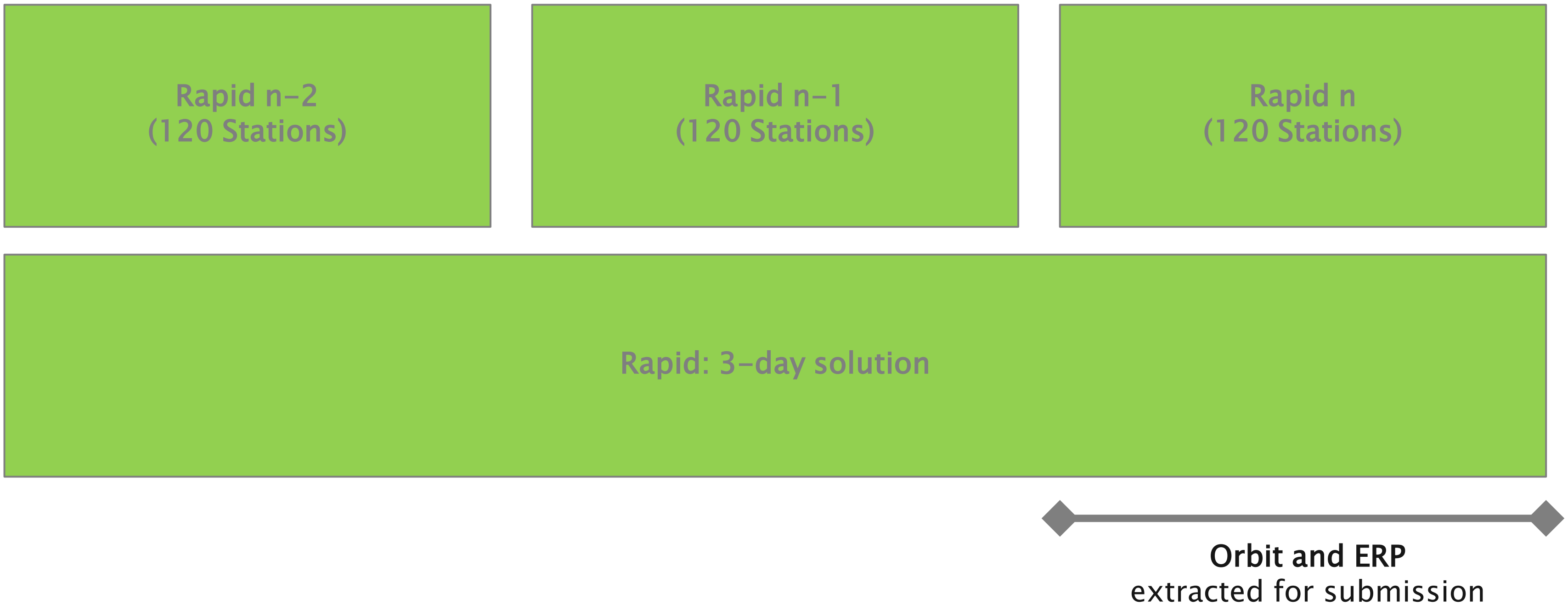

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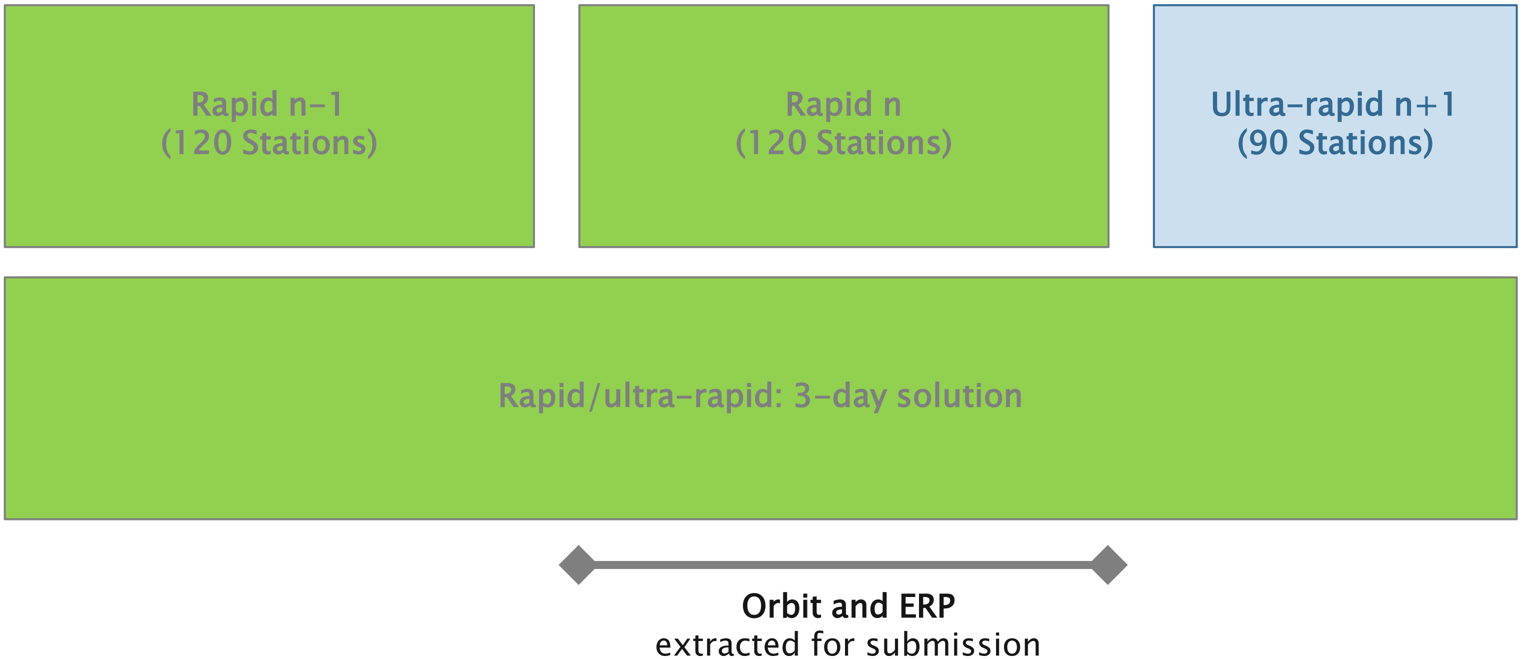
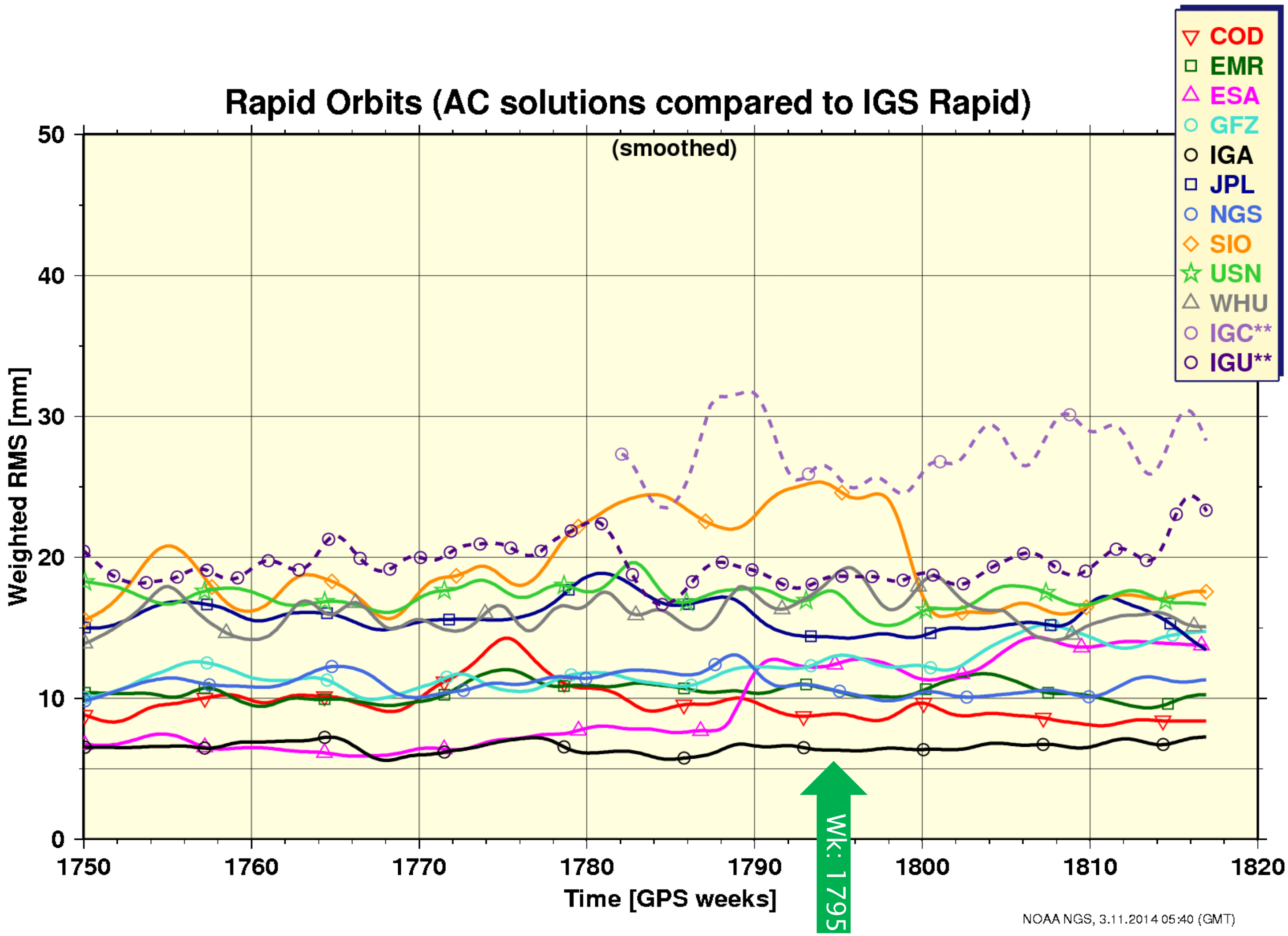


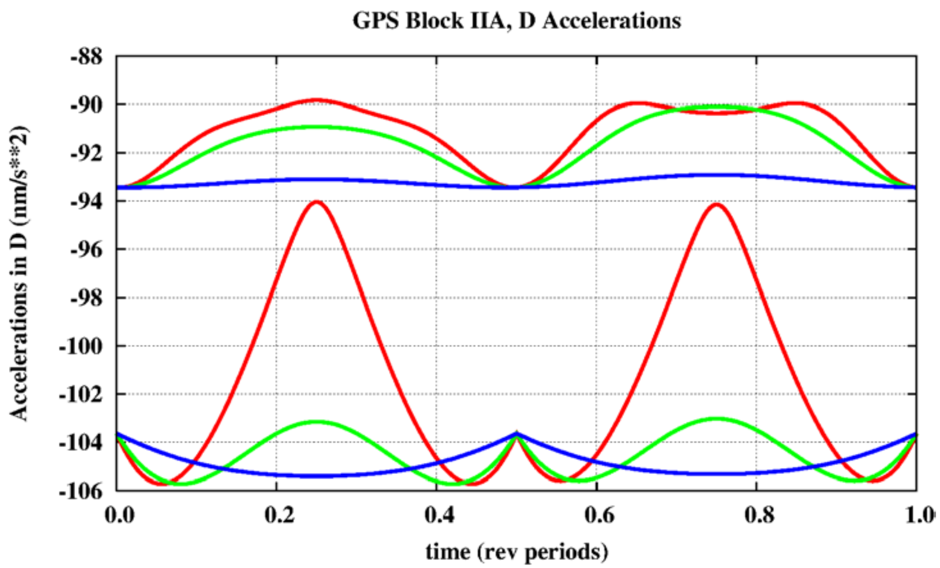
- Advantage: the submitted part is not the last part of the solution anymore.
- Disadvantage: later available, more updates of the CODE rapid solutions

Updating the CODE rapid product



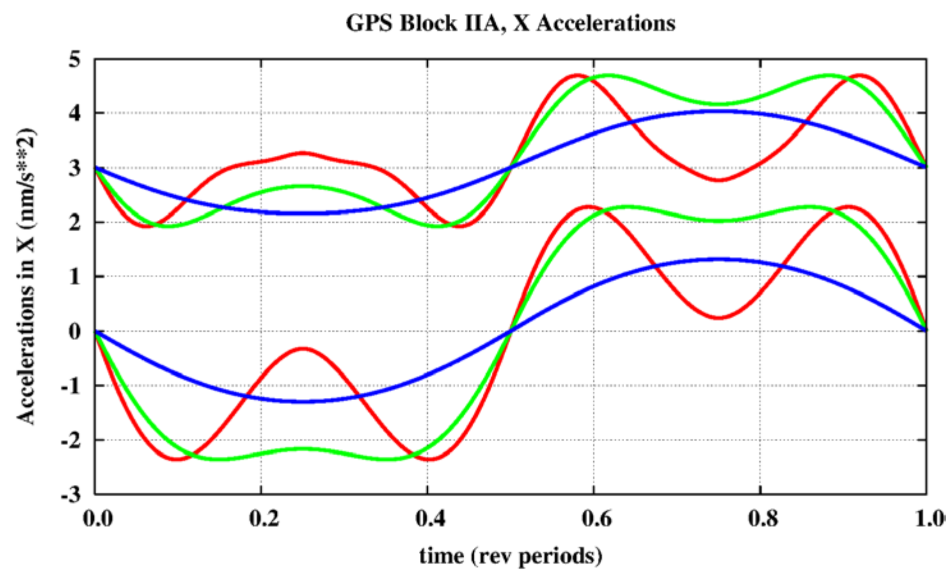
Improving the empirical CODE orbit model

Accelerations for GPS (Block IIA) satellites



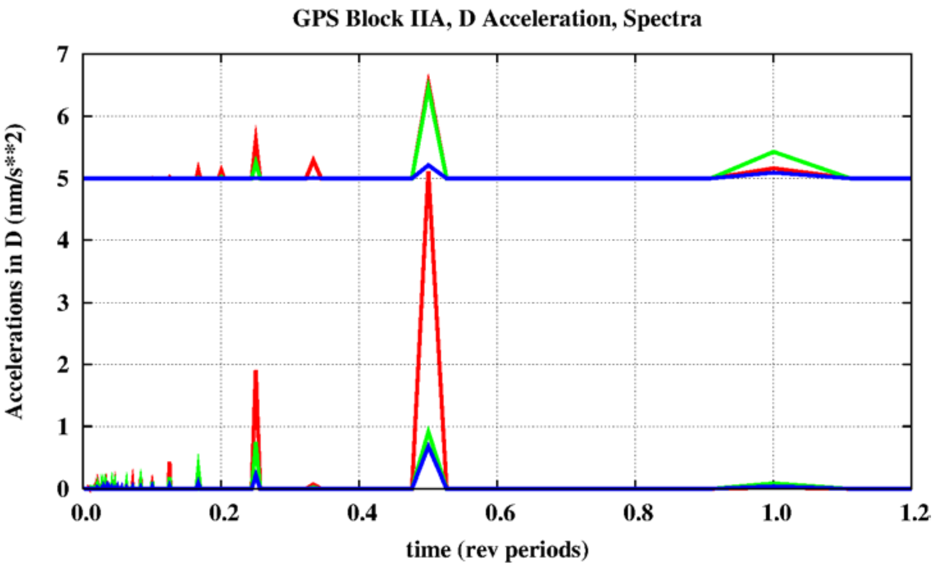
Rock-S model (shifted)
(Fliegel et al., 1992)

boxwing model
(Rodriguez—Solano et al,



Elevation of the Sun
above the orbital plane:
10° 45° 78°

Accelerations for GPS (Block IIA) satellites



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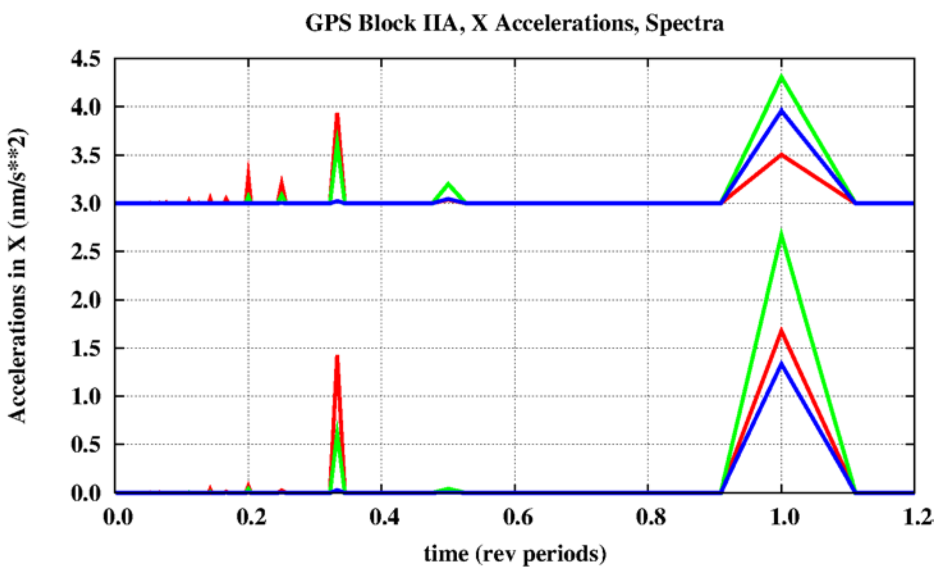


Elevation of the Sun
above the orbital plane:
10° 45° 78°

Old and new ECOM

- **The old (reduced) ECOM:**

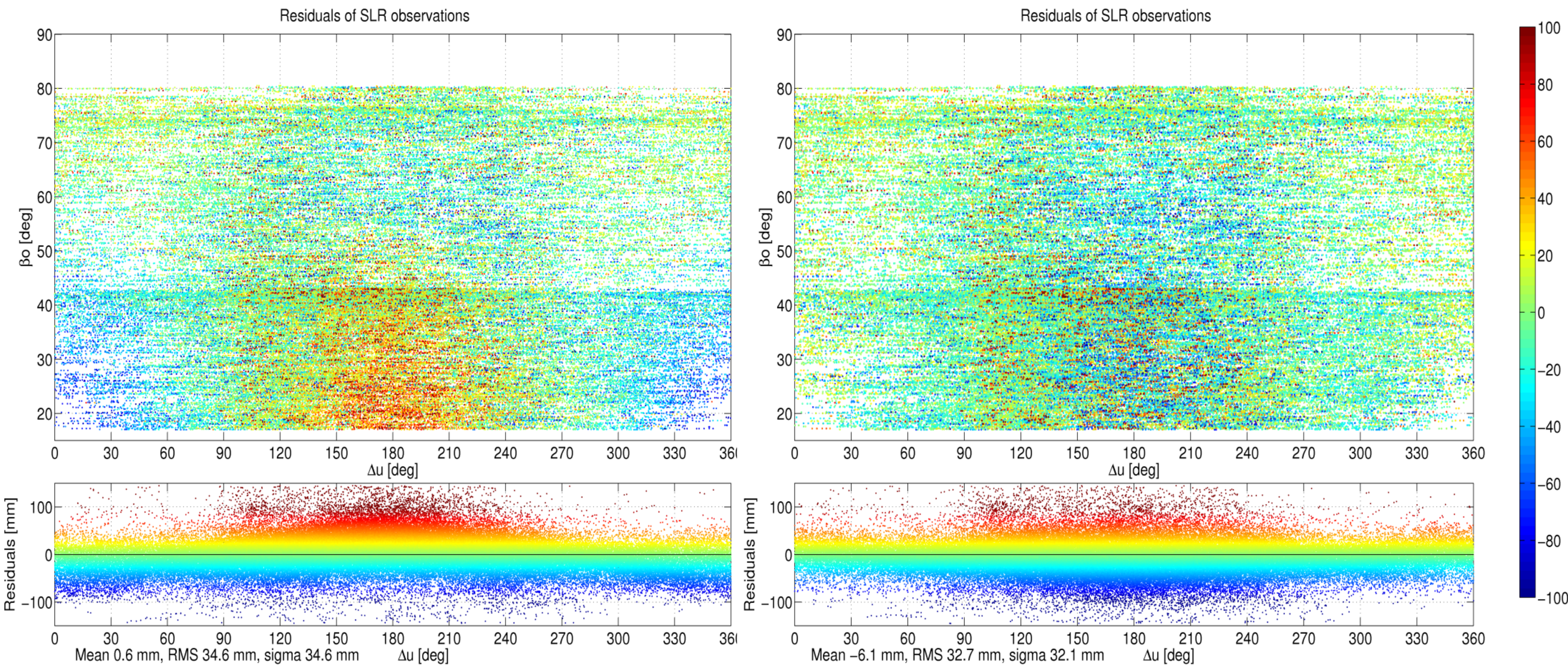
$$\vec{a}_{srp} = \vec{a}_{srp,0} + D(u)\vec{e}_D + Y(u)\vec{e}_Y + X(u)\vec{e}_X$$

$$D(u) = D_0$$
$$Y(u) = Y_0$$
$$X(u) = X_0 + X_{c,old}\cos u + X_{s,old}\sin u$$

- **The new ECOM is proposed as:** $\Delta u \doteq u - u_s$

$$D(u) = D_0 + \sum_{i=1}^{n_D} \{D_{c,2i-1}\cos(2i)\Delta u + D_{s,2i-1}\sin(2i)\Delta u\}$$
$$Y(u) = Y_0$$
$$X(u) = X_0 + \sum_{i=1}^{n_X} \{X_{c,2i-1}\cos(2i-1)\Delta u + X_{s,2i-1}\sin(2i-1)\Delta u\}$$

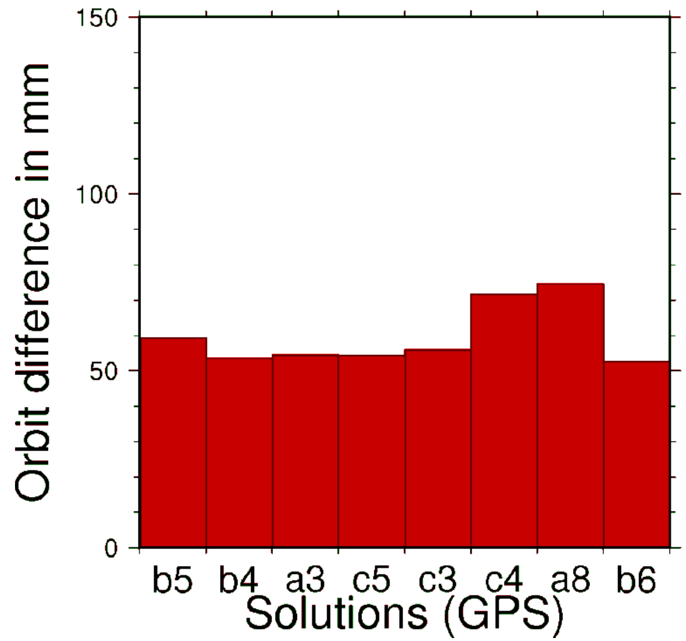
SLR Validation: GLONASS

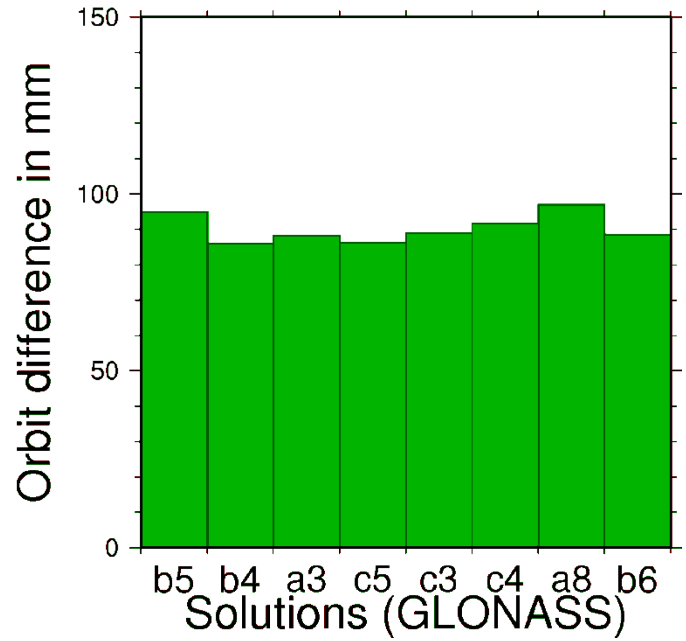


old model **new model: X_1+D_2**

Candidate New ECOMs

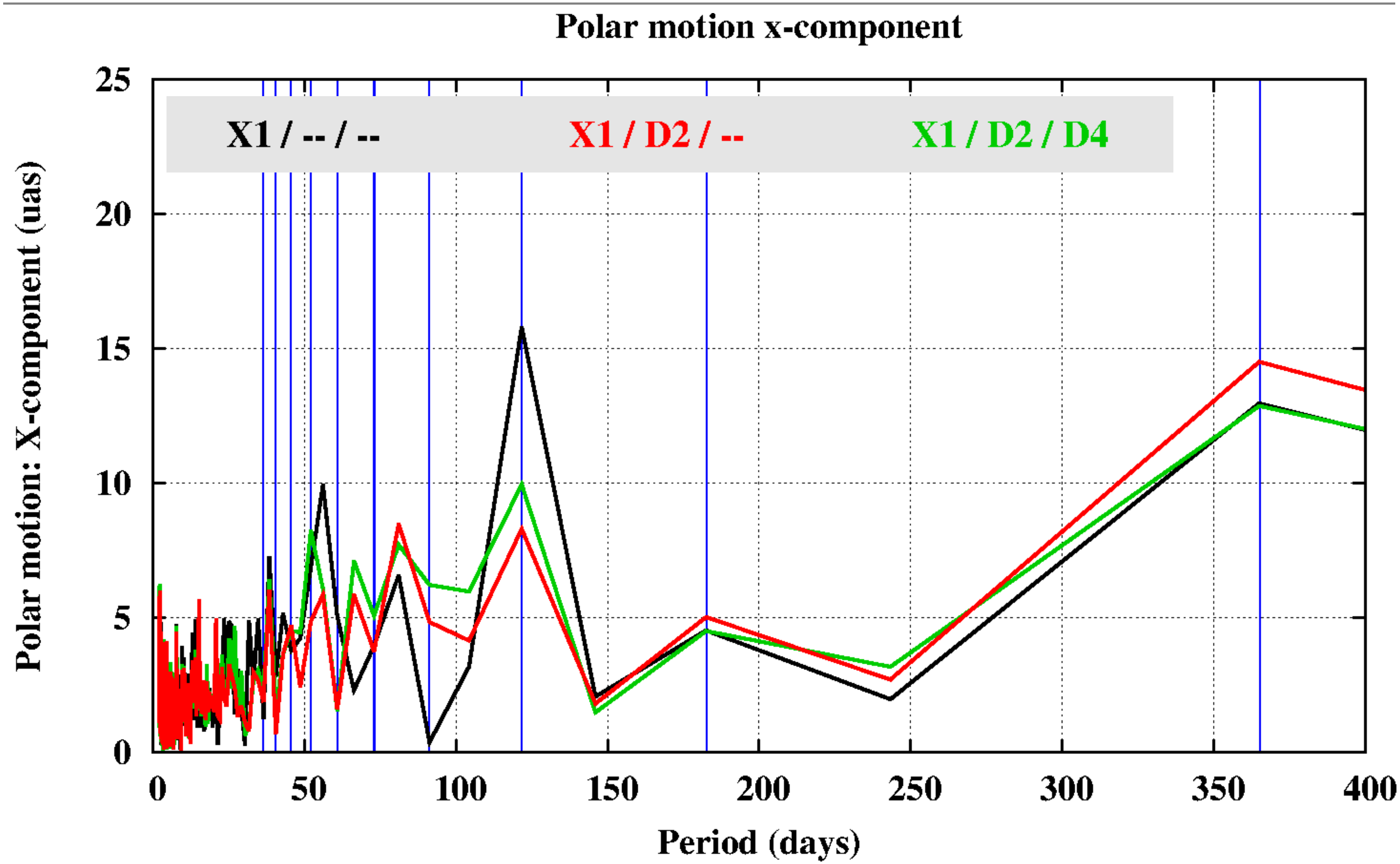
Overlaps of 1-day orbits at midnight (mean value)





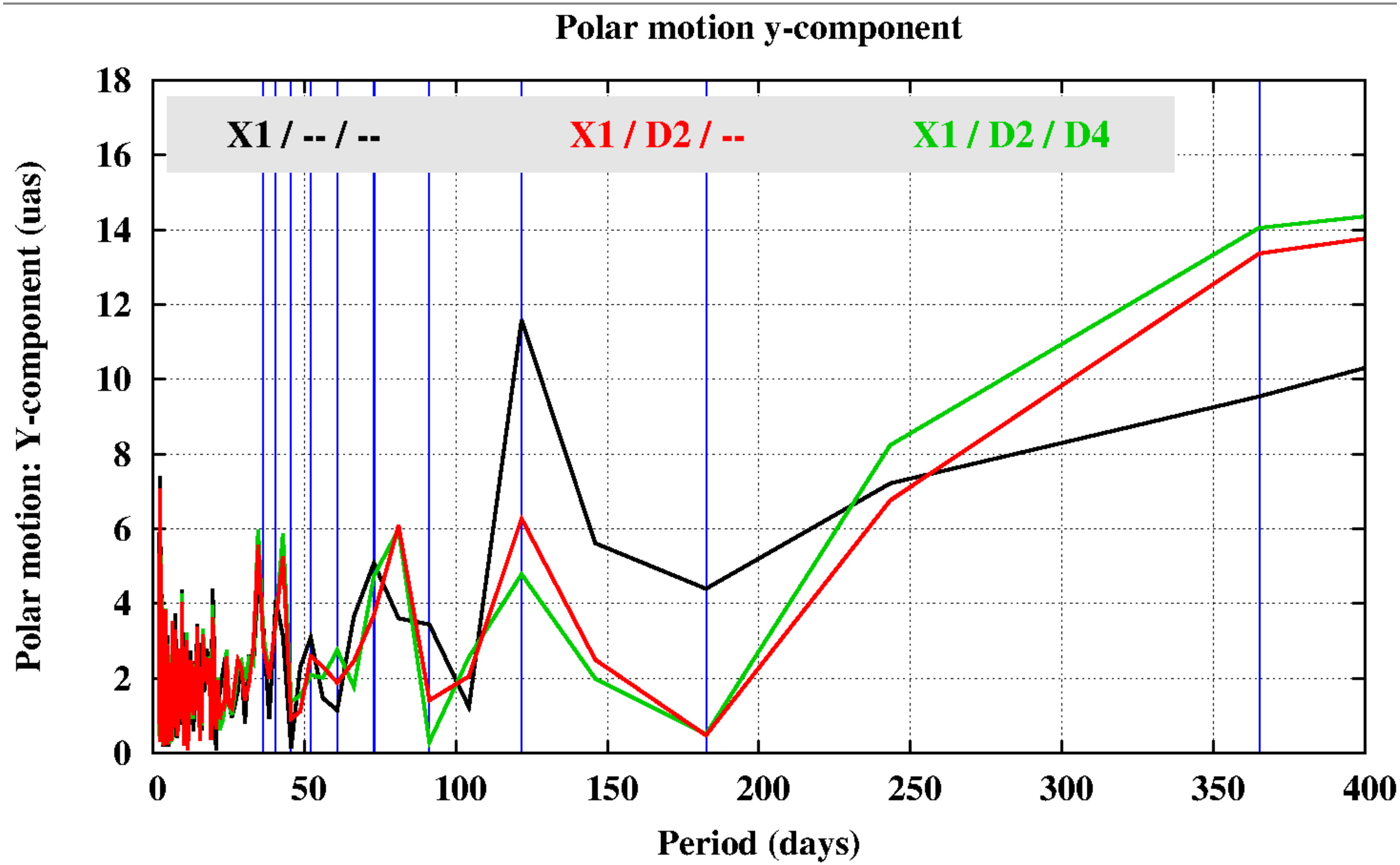
- **b5:** old model estimated parameter – X_1
- **b4:** new model estimated parameter – X_1+D_2
- **c5:** new model estimated parameter – $X_1+D_2+D_4$

Influence on Earth rotation parameters



Differences w.r.t. IERS C04 series have been analyzed.

Influence on Earth rotation parameters



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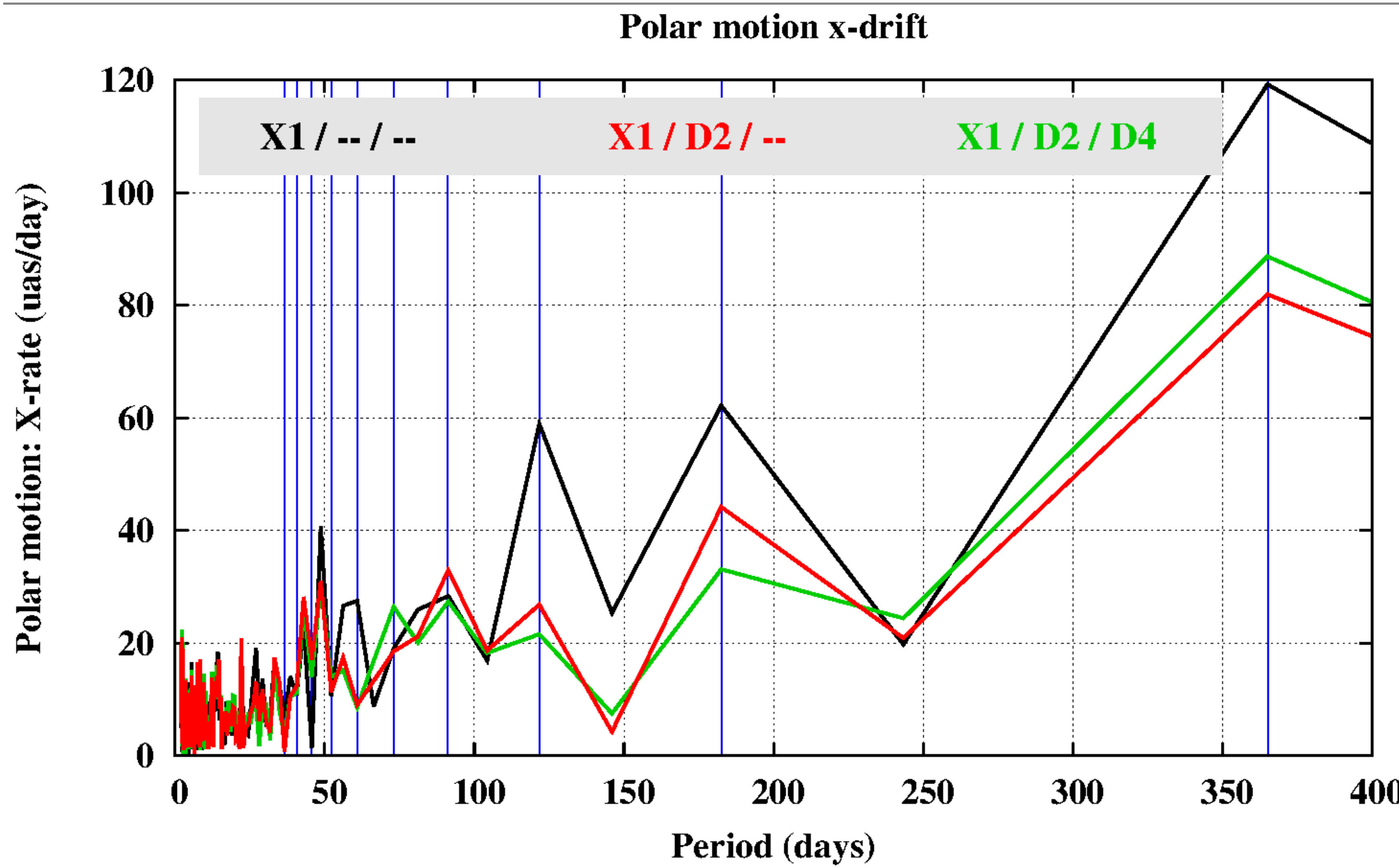

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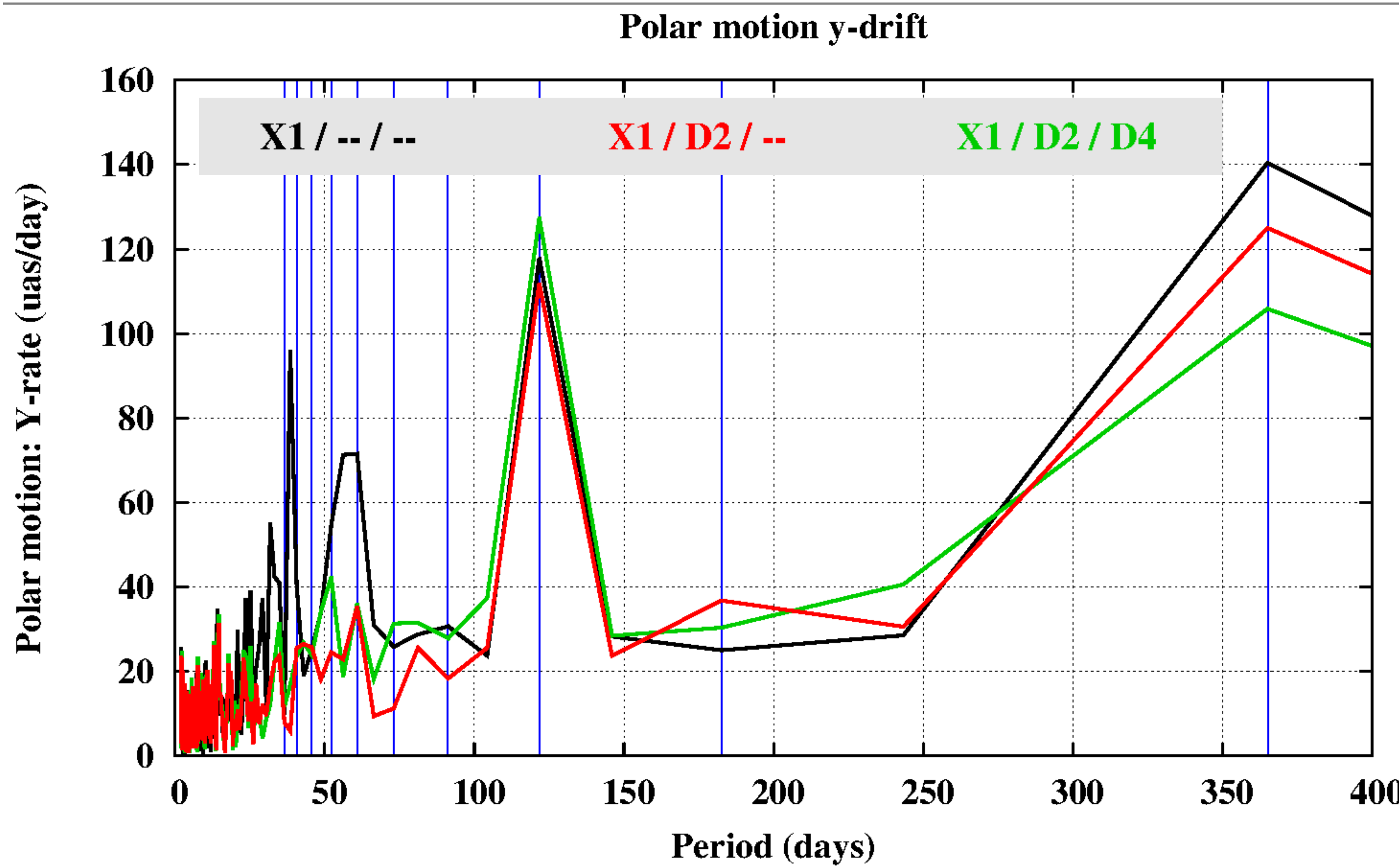


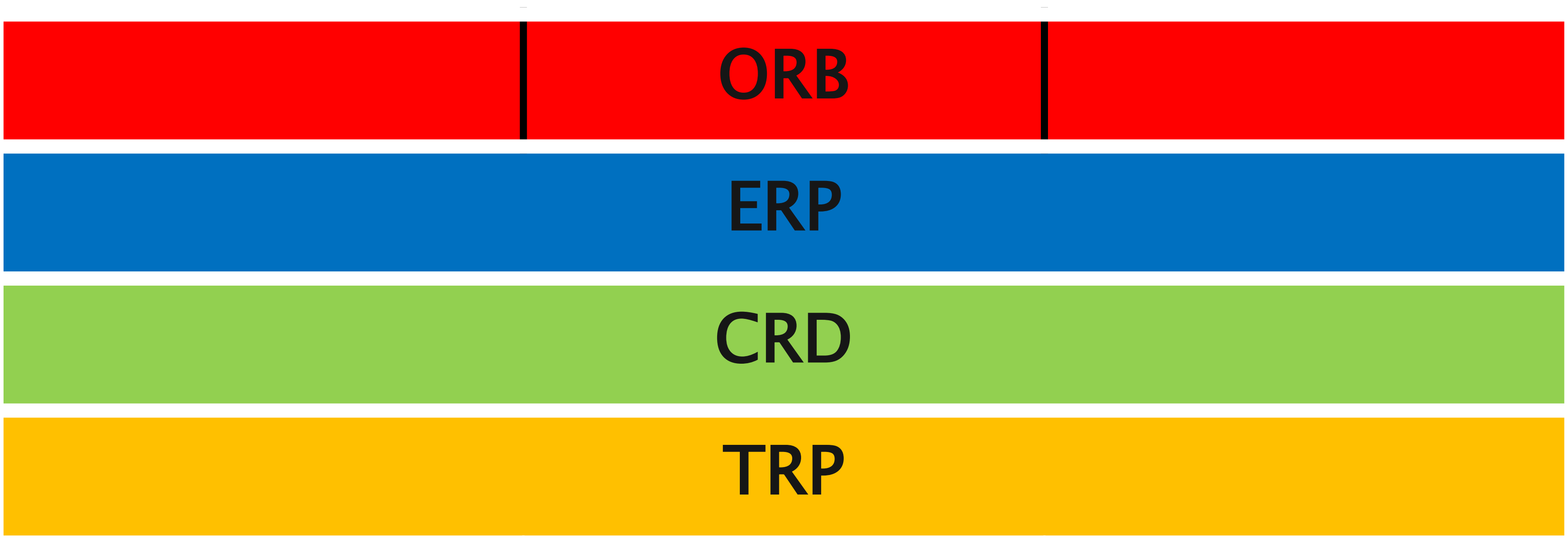
Differences w.r.t. IERS C04 series have been analyzed.

Multi-day solutions

Strategy for the long–arc solution

Classical approach to generate 3–day solutions at CODE:

NEQ from long–arc solution for day ±0

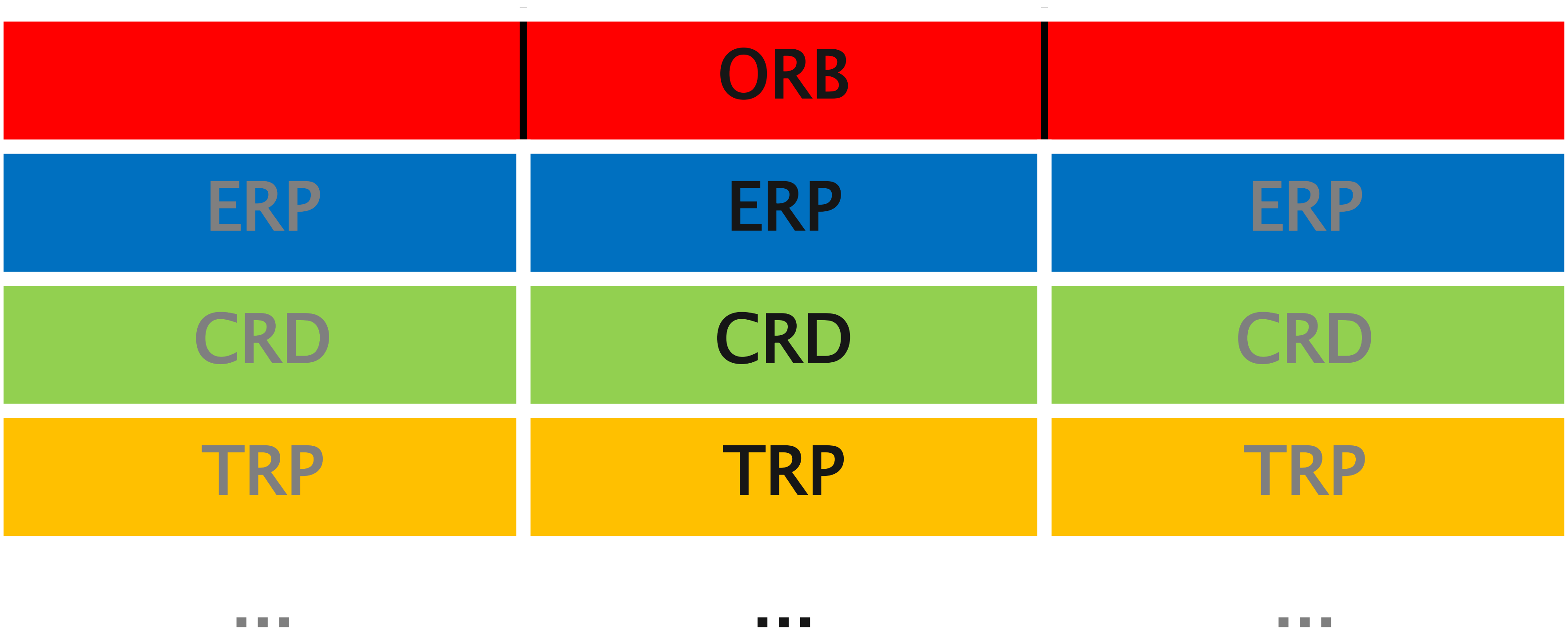


...

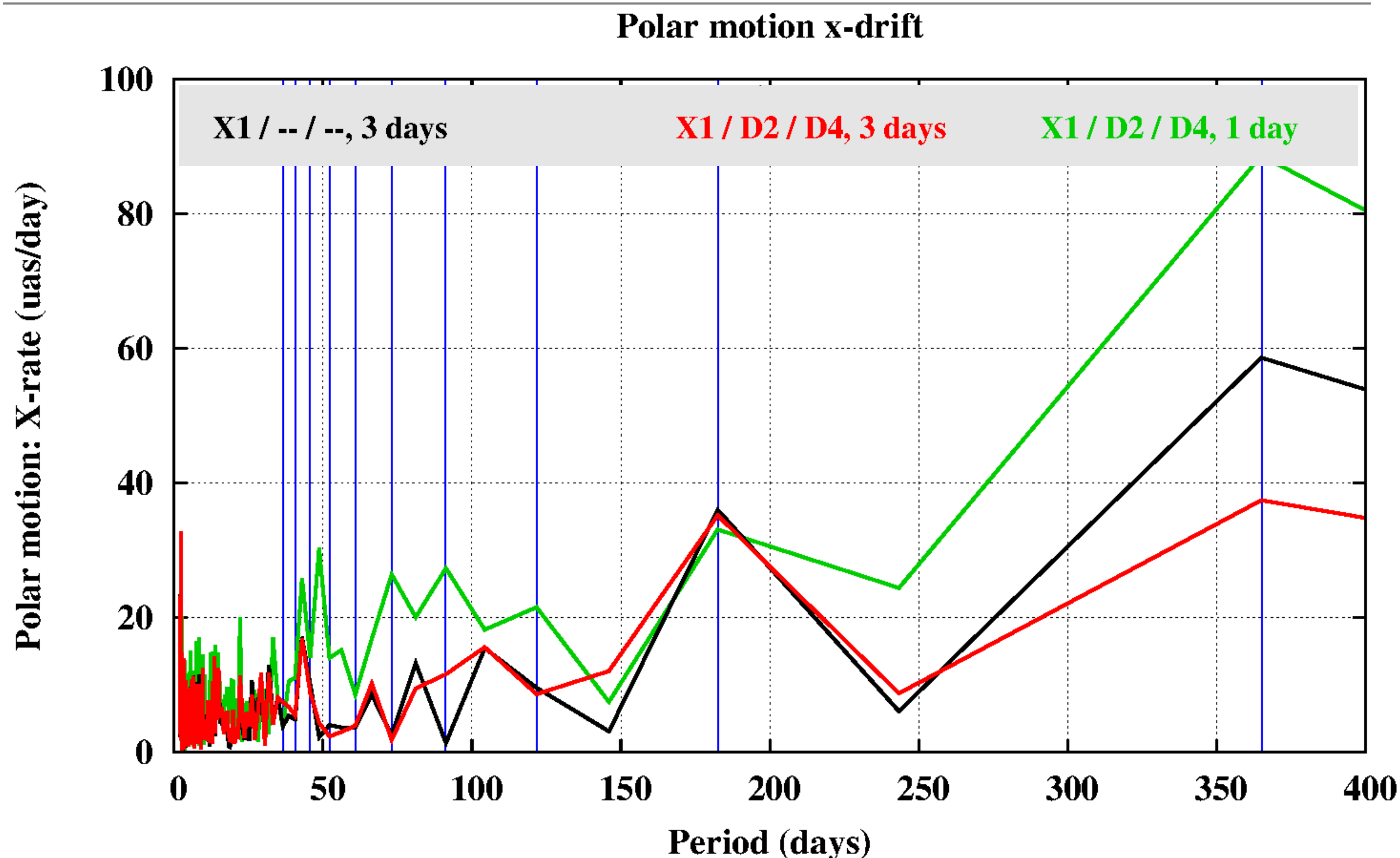
Strategy for the long-arc solution

Alternative approach for a 3-day long-arc solutions

NEQ from long-arc solution for day ±0



Influence on Earth rotation parameters



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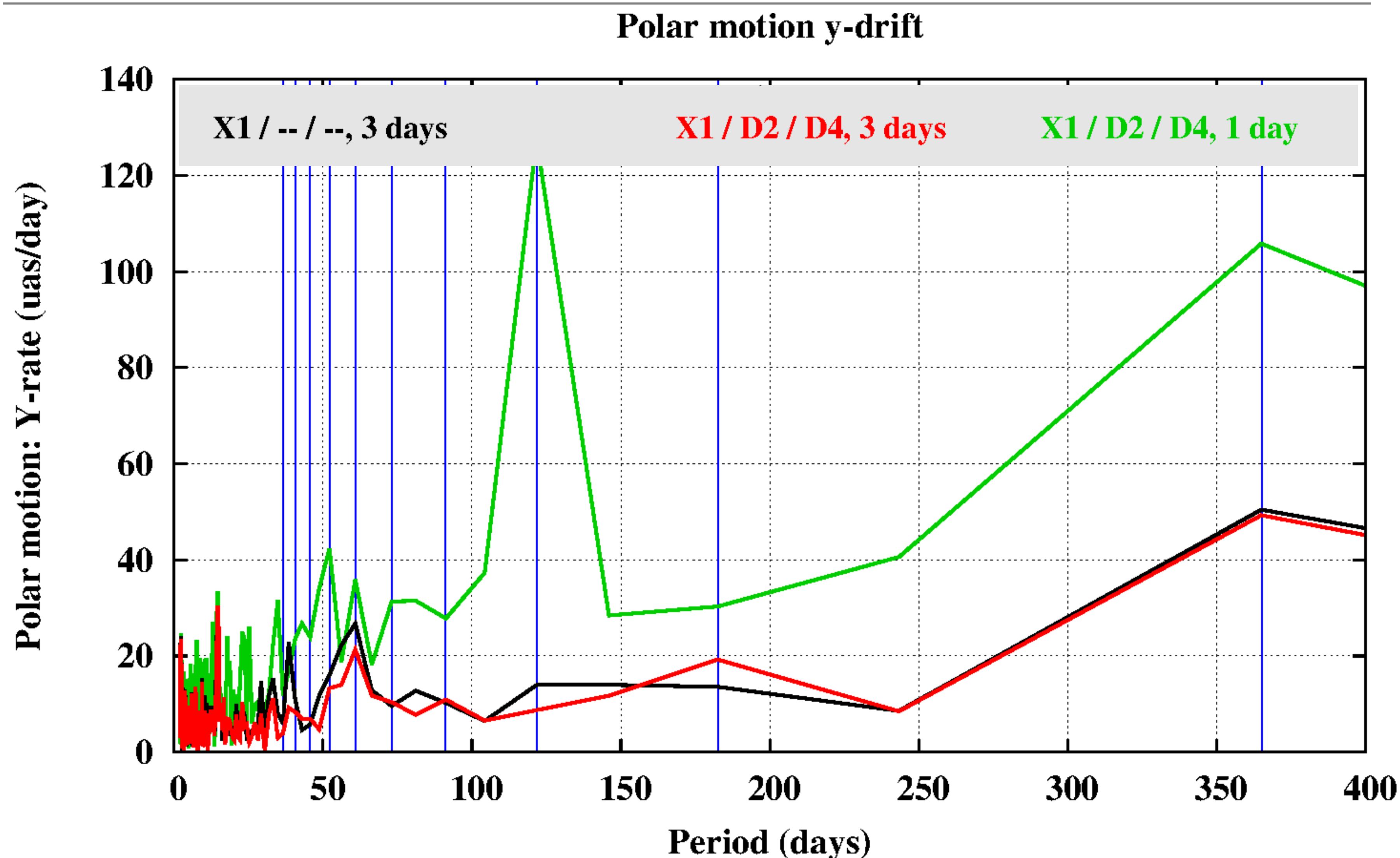

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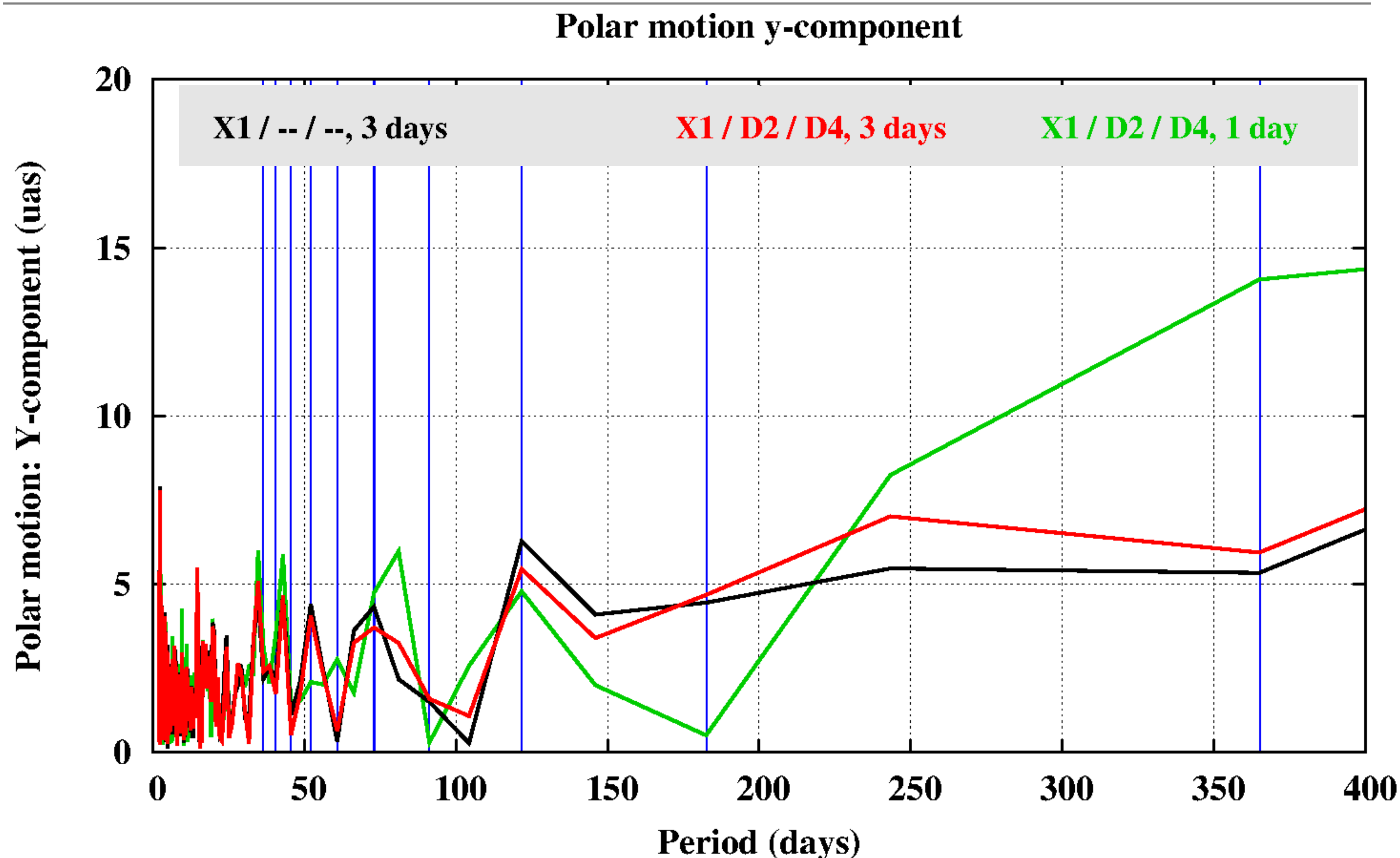


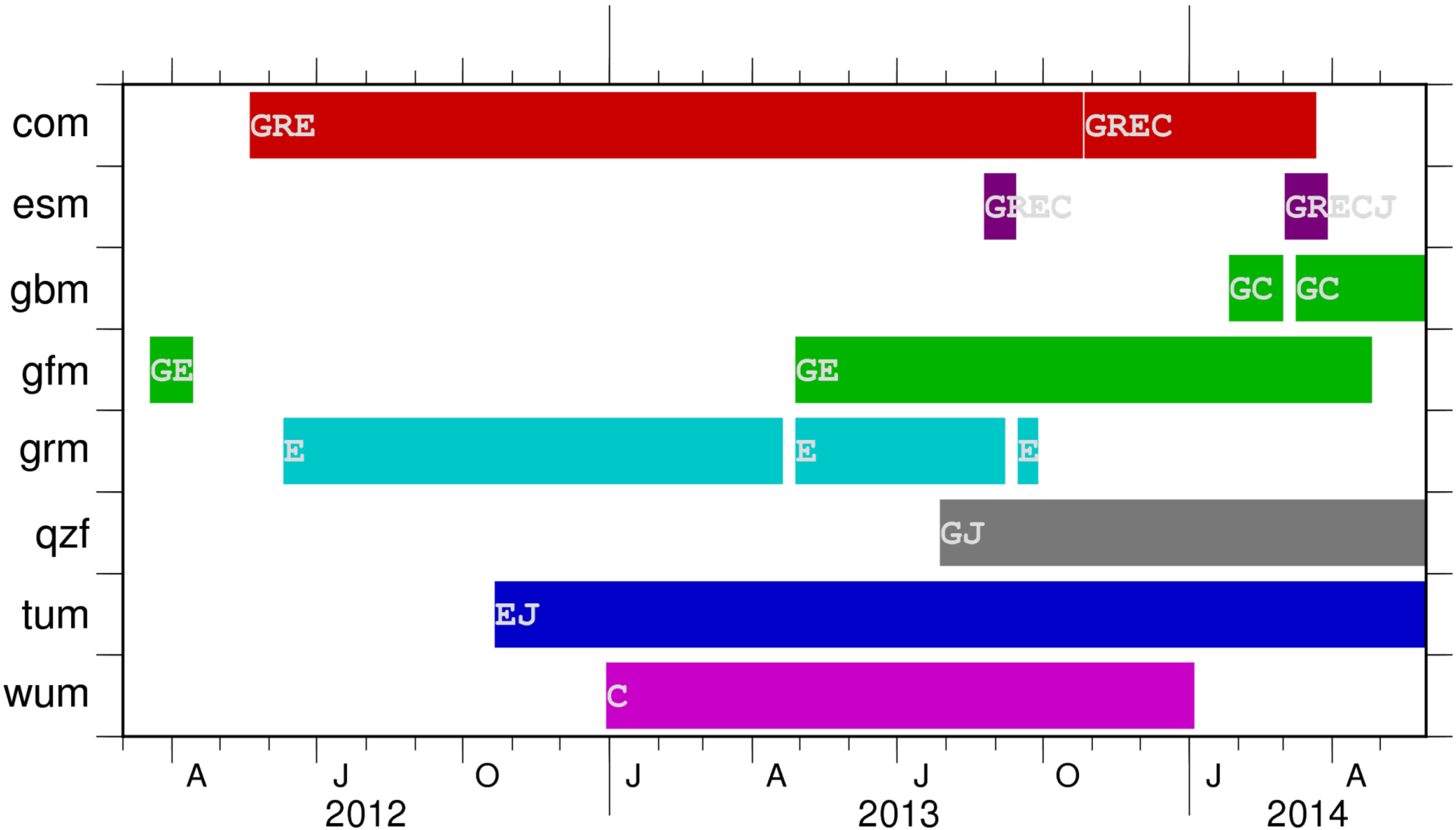
Differences w.r.t. IERS C04 series have been analyzed.

CODE-contribution to IGS Multi-GNSS Experiment (MGEX)

Software developments for MGEX

- BSW 5.2: limited to max. 3 different GNSS at the same time due to „bottle necks“ in many locations in the software
- Those bottle necks and limitations have mostly been replaced by a more generic GNSS handling that will simplify the addition of new GNSS in the future
- Capability to process BeiDou, QZSS, SBAS has been added
- Software changes were merged into the current internal version of the Bernese GNSS Software as contribution to the release of the next BSW version
- Capability to process GPS, GLONASS, Galileo, BeiDou together has been demonstrated using MGEX data; currently a solution extended to QZSS is tested

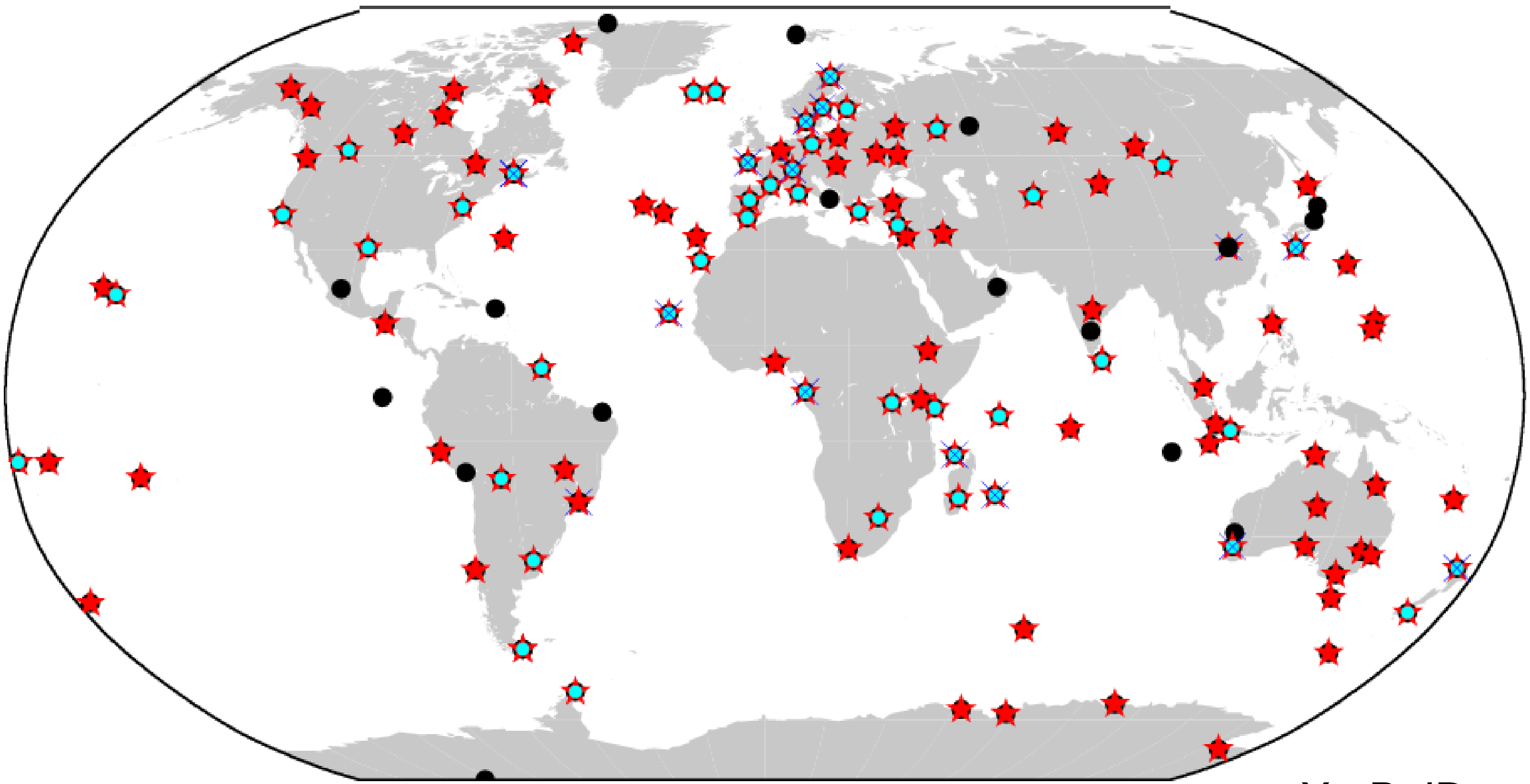
MGEX products (all ACs)



Status June 2014

CODE MGEX: network

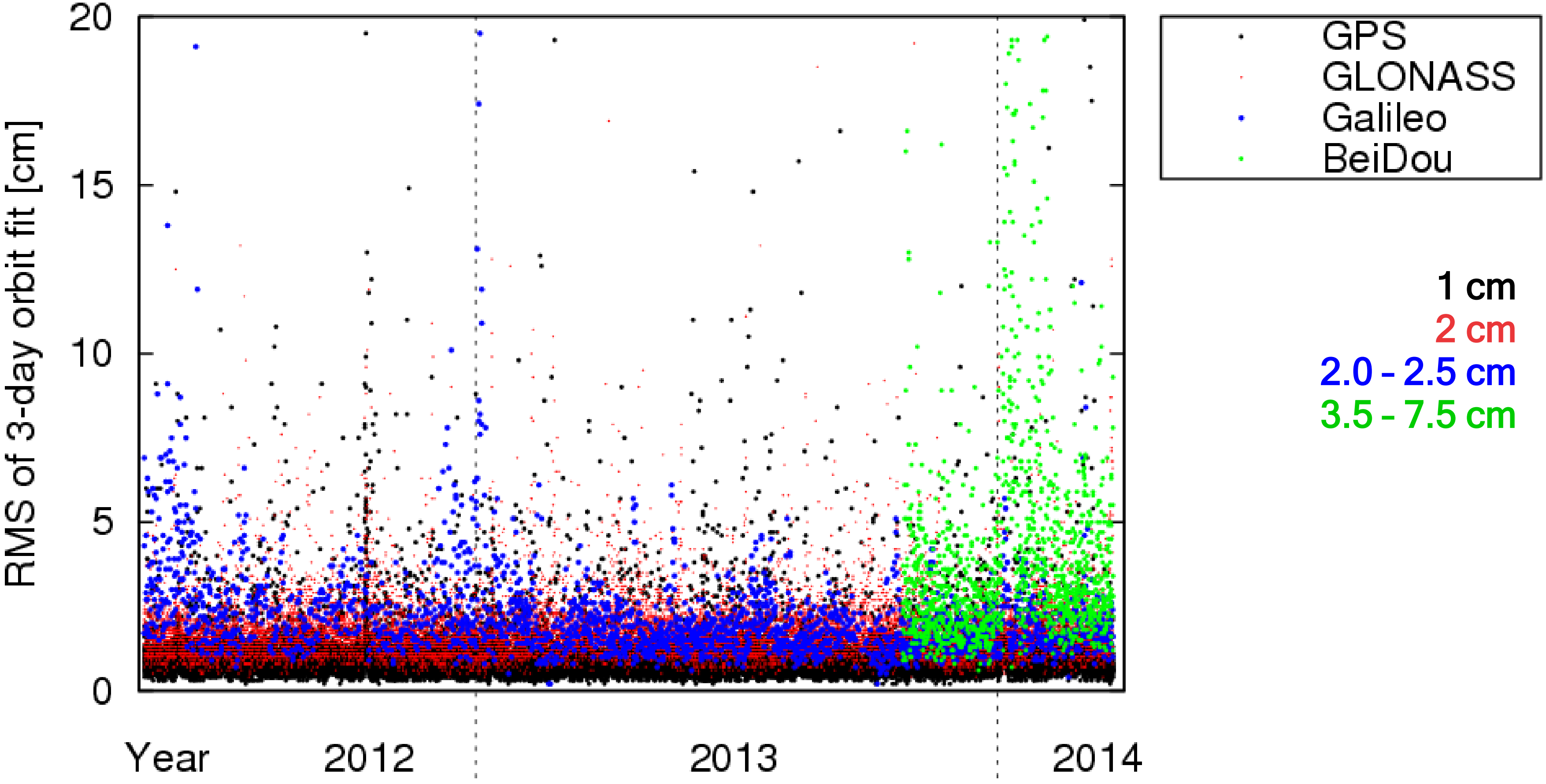
- **Number and distribution of tracking stations contributing to the CODE MGEX solution (mid 2014)**



• GPS: 130 ★ GLONASS: 120 • Galileo: 30 X BeiDou: 20

CODE MGEX orbit solution

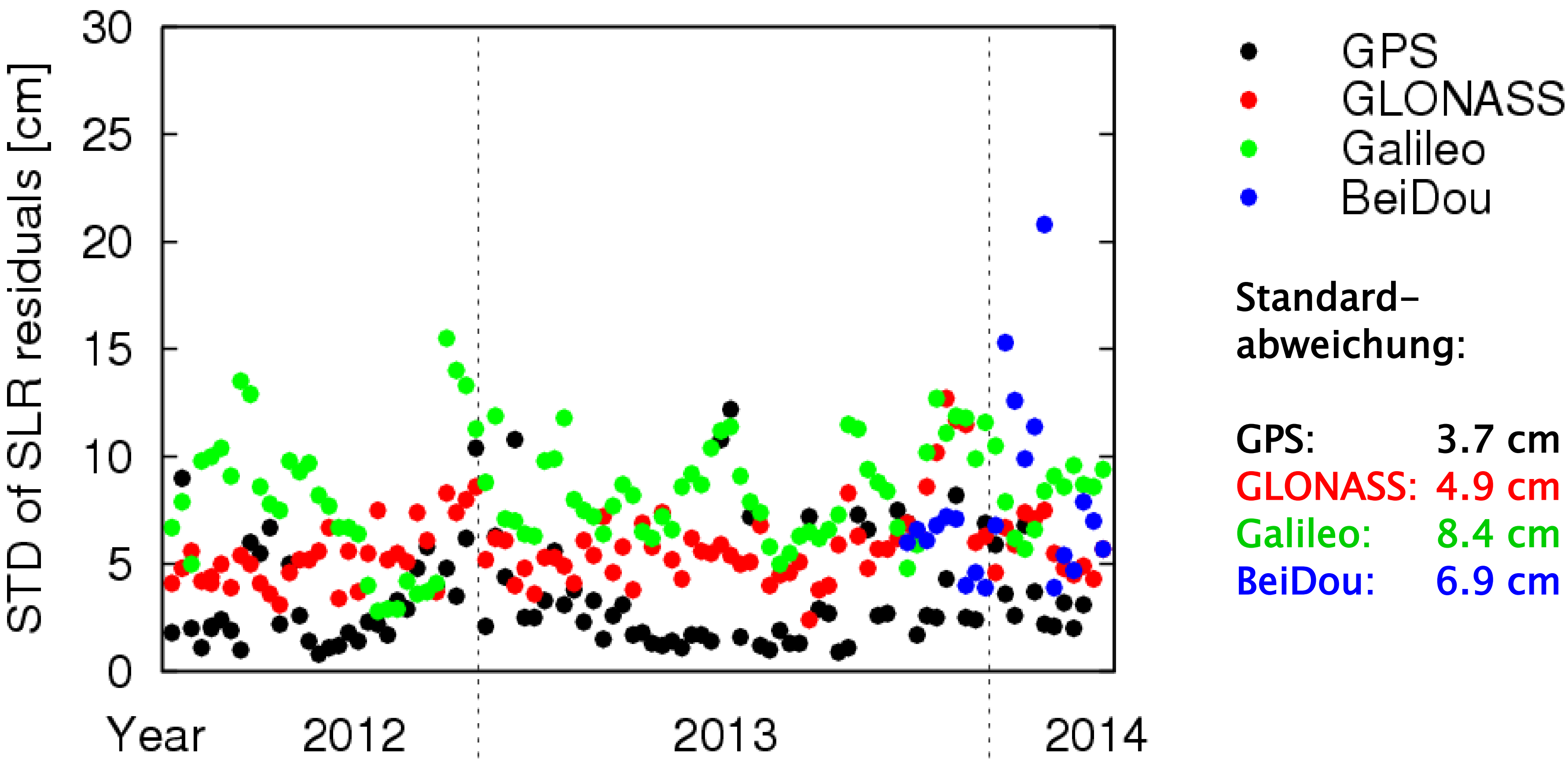
- Orbit validation : 3-day orbit fit



1 cm
2 cm
2.0 - 2.5 cm
3.5 - 7.5 cm

CODE MGEX orbit solution

- **STD of SLR residuals per week: GNSS-wise**



Standard-abweichung:

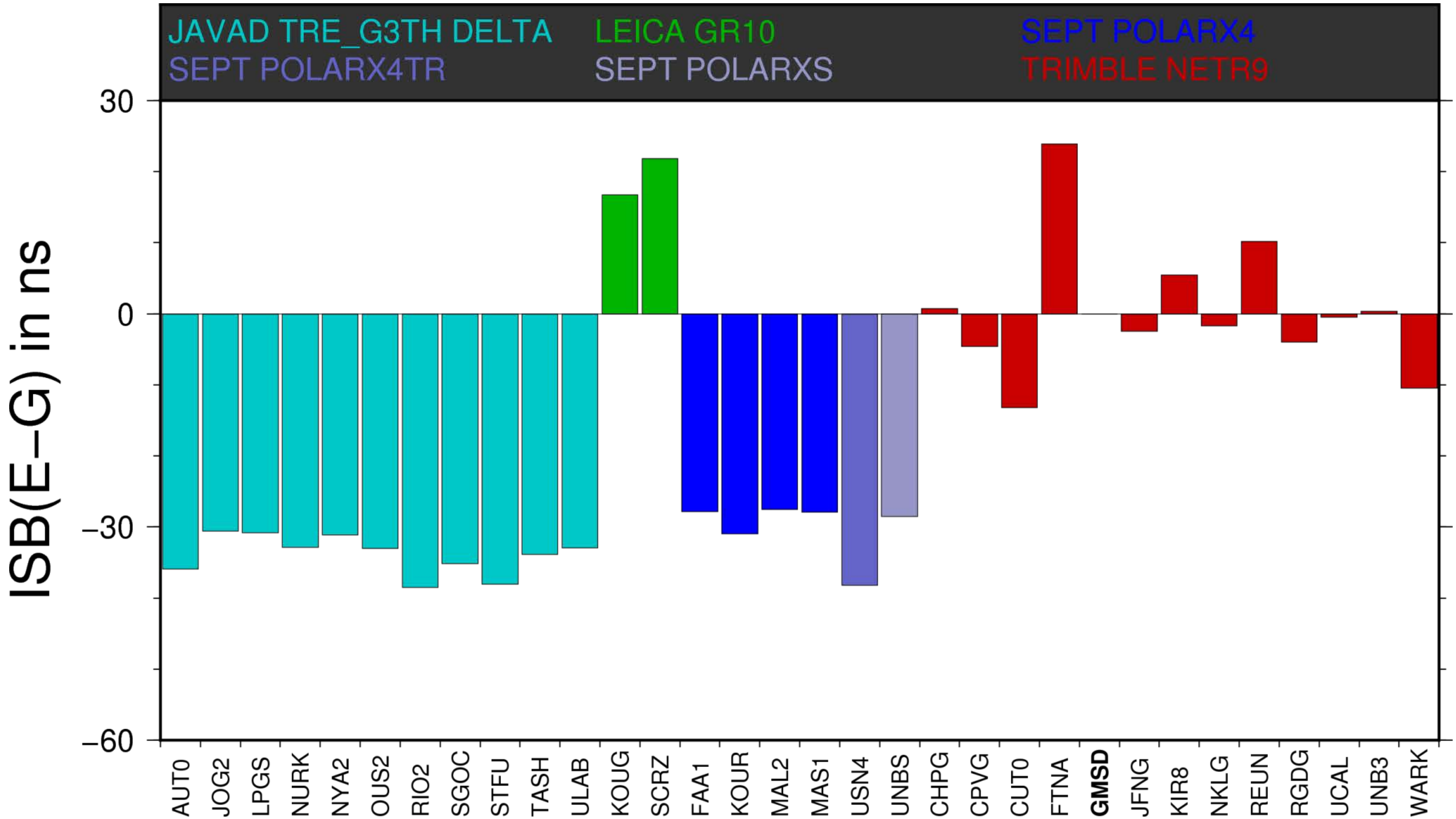
GPS:	**3.7 cm**
GLONASS:	**4.9 cm**
Galileo:	**8.4 cm**
BeiDou:	**6.9 cm**

PPP with CODE MGEX products (7 days)

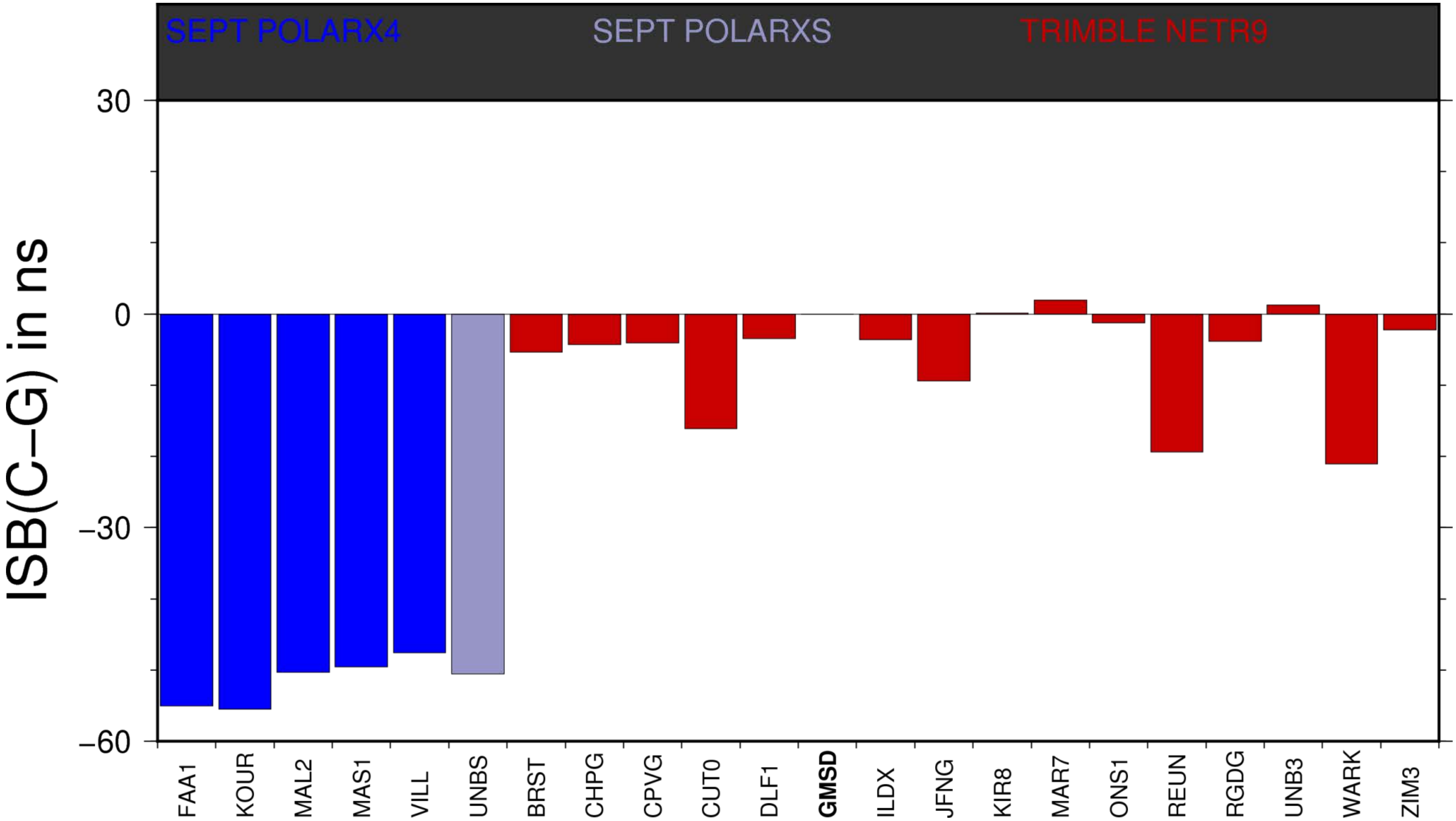
Difference to CODE MGEX network solution (<3 dm): BeiDou only, GPS only, GPS+BeiDou+Galileo

Mode	Static						Kinematic					
Station	North		East		Up		North		East		Up	
	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD
JFNG	0.3	0.1	0.0	0.8	1.3	1.1	-0.7	6.2	-2.0	9.3	13.3	26.5
	0.1	0.1	0.1	0.1	0.3	0.2	0.7	2.1	0.1	2.5	8.8	14.4
	0.3	0.1	0.0	0.1	0.4	0.3	0.3	1.1	0.0	1.0	8.6	13.1
KIR8	-0.5	1.5	2.5	3.3	0.2	0.8	65.0	157.2	23.7	190.4	-31.0	299.6
	0.1	0.2	-0.3	0.1	-0.7	0.3	0.5	1.7	-0.2	1.9	-4.1	7.5
	0.1	0.2	-0.2	0.1	-0.5	0.4	0.4	1.1	-0.2	1.2	-4.0	7.2
UNB3	-4.4	25.6	-24.4	22.3	5.3	10.3	---	---	---	---	---	---
	0.0	0.1	0.0	0.2	-0.6	0.4	0.0	2.9	0.4	4.2	10.3	14.4
	0.0	0.1	0.1	0.3	-0.2	0.5	-0.1	2.4	0.3	3.4	10.3	13.8
WARK	-0.1	9.9	1.6	8.8	-4.1	14.1	-5.4	116.9	49.7	194.7	-15.6	2281
	0.2	0.1	0.2	0.2	-1.1	0.4	-0.5	2.7	0.6	4.3	19.3	8.6
	0.2	0.1	0.3	0.2	-0.8	0.4	-0.1	2.0	0.3	3.1	18.9	8.4

CODE MGEX: Inter-system biases Galileo



CODE MGEX: Inter–system biases BeiDou



Combination of inhomogeneous multi-GNSS products

(ESA/NPI-project with ESOC)

Developing a new IGS combination software

- Anforderungen an eine IGS Kombinationssoftware der Zukunft:
  - Verschiedenartige in sich konsistente multi-GNSS Lösungen müssen zusammengeführt werden (Bahnen, Uhren, Biases)
    - AC1 GPS + GLONASS
    - AC2 GPS
    - AC3 GPS + Galileo
    - AC4 GPS + GLONASS + Galileo + Compass + QZSS
    - AC5 Galileo
    - . . .
    - IGS GPS + GLONASS + Galileo + Compass + QZSS
  - PPP-Mehrdeutigkeitslösung

Updating the pre-processing scheme

Unified Zero-Difference Preprocessor

- Preprocessing: data editing before the each parameter estimation procedure
- Motivations:
  - Currently, every single processing has its own preprocessing
  - If a station is used in *n* different processing, it means that it is preprocessed *n* times, and usually in different ways
- Replace all preprocessing by a single (consistent) one based on PPP

STEP 2:

- Densification of the estimated (600s) clocks from STEP 1 down to the highest needed sampling rate (e.g 30s) (program CLKEST of BSW)
- Optimized for speed (station selection)
- Critical aspect: completeness of the satellite high-rate clocks

STEP 1

Production of orbits and 600 s satellite clocks

STEP 2

Production of 30 s satellite clocks

STEP 3

PPP data editing

Multi-GNSS data editing, problematic satellites

Quickest way through the procedure:

1. Step 1 and 2 only for «good» satellites of one GNSS (e.g., GPS)
2. Add remaining satellites (e.g., unhealthy or repoitioning or alternative systems) in an independent step.

All station-related information may be introduced: CRD, TRP, ERP, receiver CLK

Bookkeeping: which observation was already cleaned and which not...

Other activities in the context of CODE/IGS processing

Other activities …

- RINEX3 MGEX downloading scheme using XML database is now also applied to the legacy RINEX2 data.
- Ionosphere maps are now computed with an hourly resolution and a revised processing scheme (parallelization).
- Bias-handling for multi-GNSS environment is generalized to be prepared for the new signals and systems.
- …

CODE-contribution to the ITRF

(common effort by AIUB, TUM, BKG)

Common parameters

Direct combination
(Indirect combination by applying correction terms)

	GNSS microwave	SLR @ GNSS	SLR spherical satellites
Station coordinates	GNSS	SLR	SLR
ERP	X	X	X
Geocenter	X	X	X
Orbits GNSS satellites	X	X	
Microwave Sat. antenna offsets	X		
Laser Reflector Array offsets		X	
Range Biases		X	(X)
Orbits spherical satellites			X

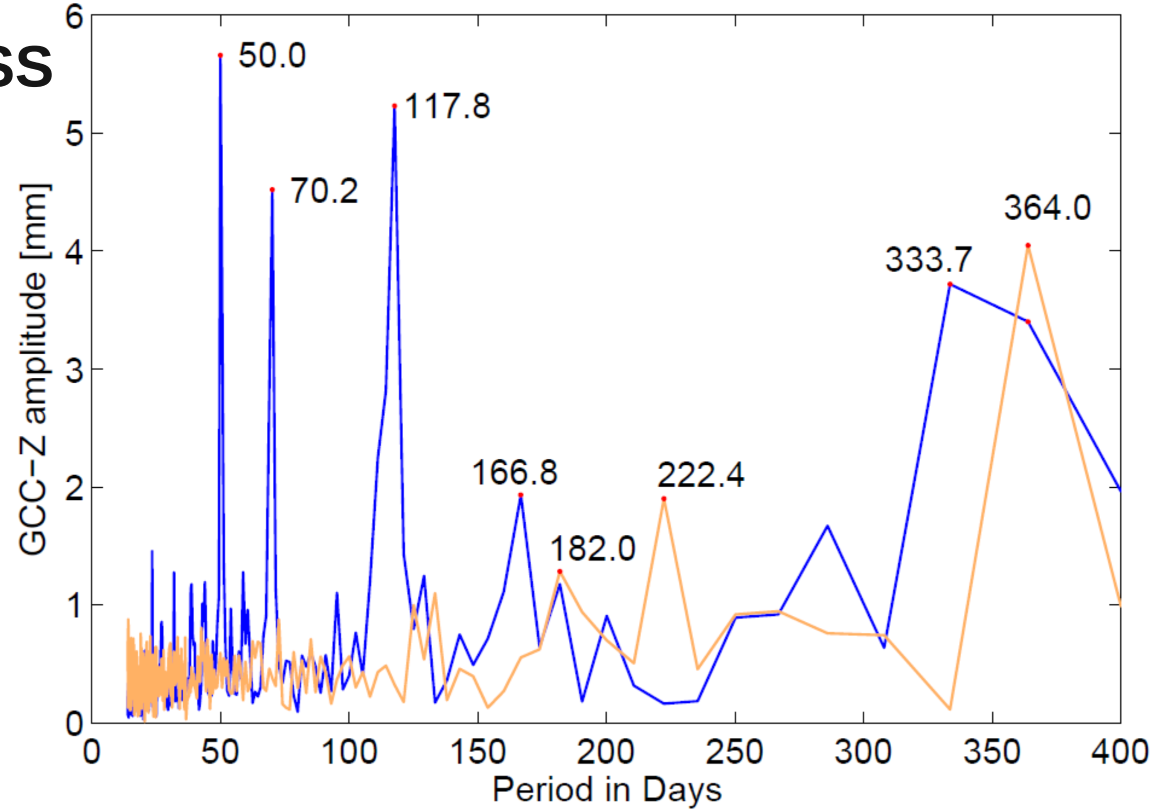
Geocenter: Single techniques

Draconitic year is visible: GNSS = 352d, LAG-2 = 222d

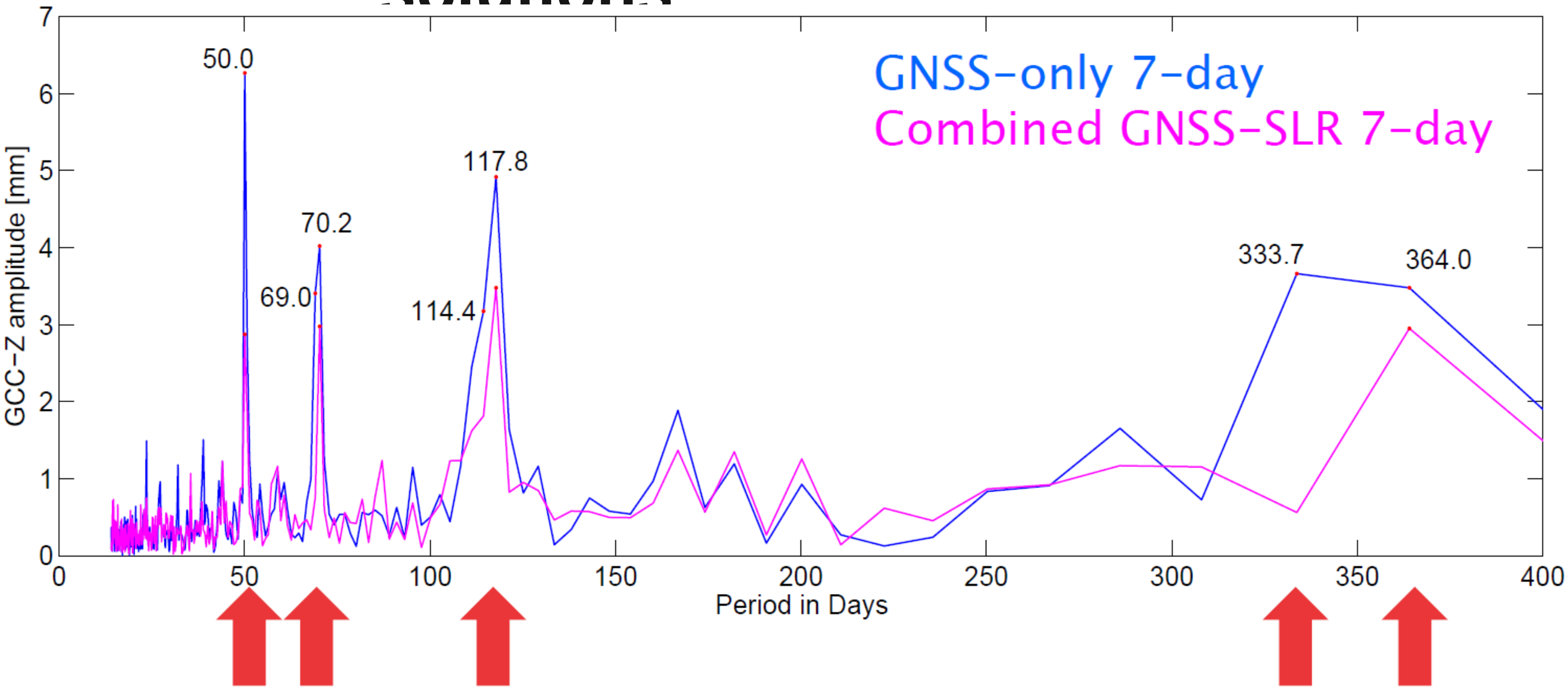
+ Harmonics for GNSS

GNSS-only

SLR-only



Geocenter: Combined solutions

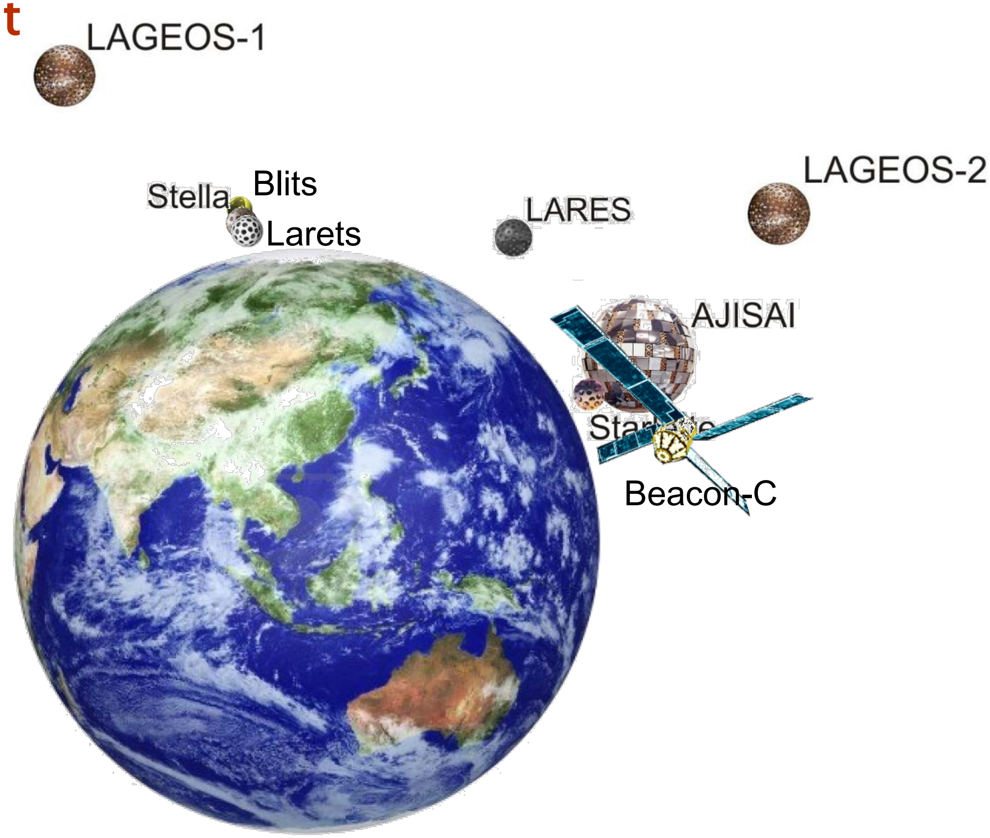


- **Annual signal remains; draconitic signals disappear**
- **Harmonics of draconitic GNSS year are reduced, but not eliminated**

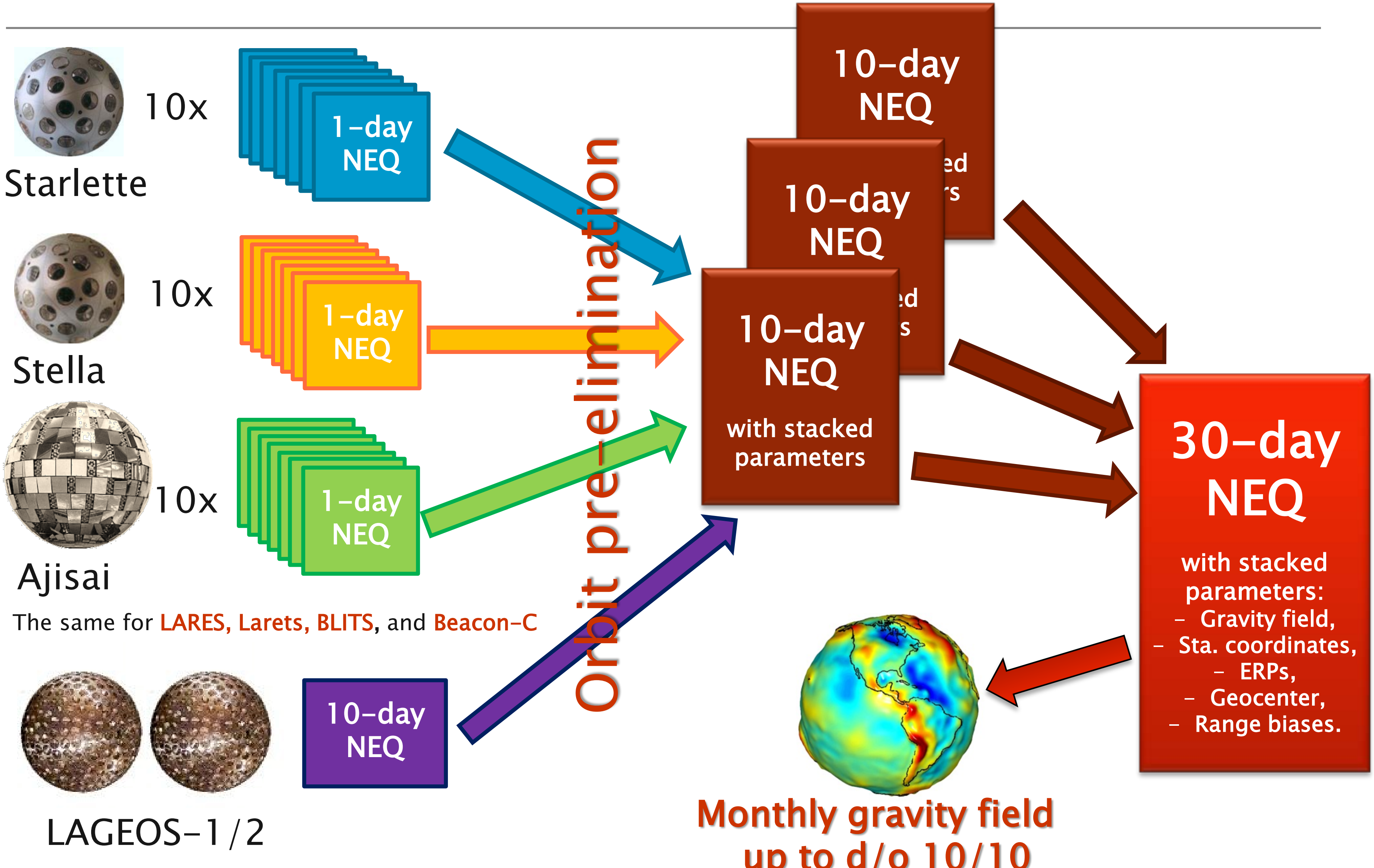
Satellite Laser Ranging (SLR) Solutions

Space Segment of SLR satellites

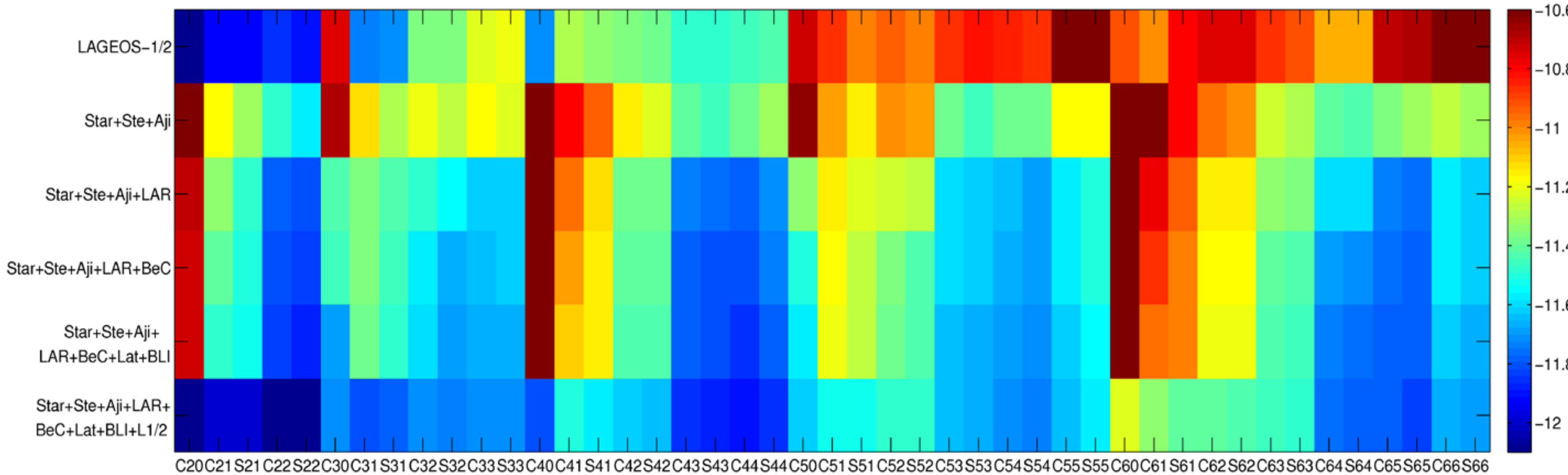
- Up to **9 SLR satellites** with **different altitudes** and **different inclinations** are used.
- For LAGEOS-1/2 **10-day long arcs** are generated without estimating once-per-revolution empirical accelerations in out-of-plane (due to correlations with C_{20}).
- For **low** orbiting **satellites 1-day arcs** are generated.
- **Different weighting** of observations is applied: from **8mm** for **LAGEOS-1/2** to **50mm** for **Beacon-C**.



Processing scheme



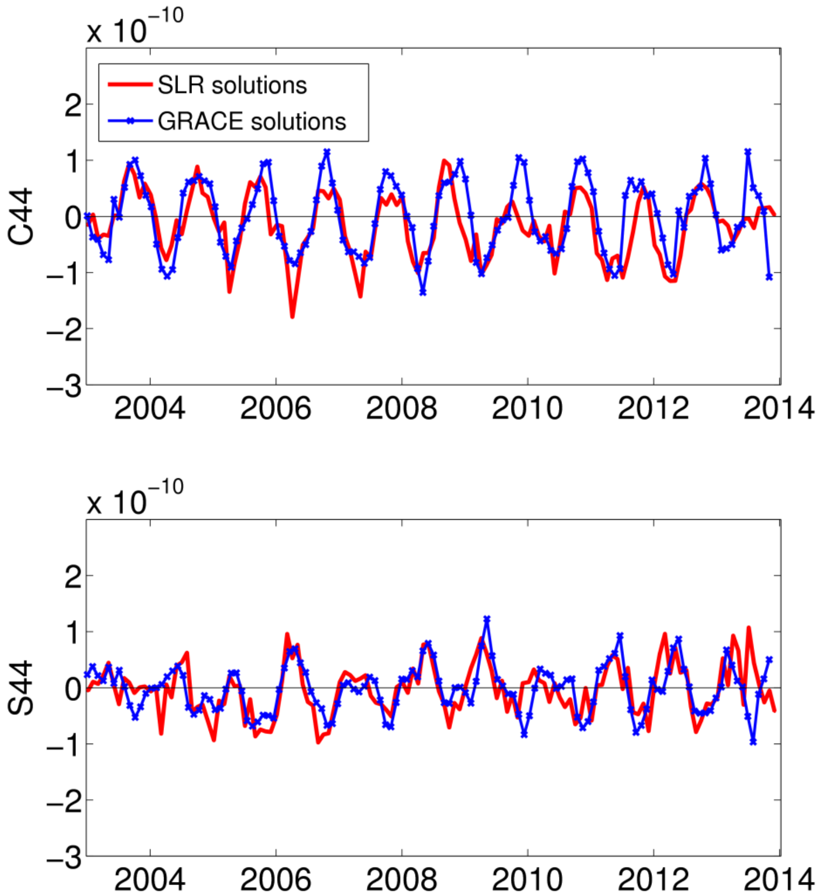
Sensitivity of SLR satellites to SH coefficients



Formal errors of coefficients up to d/o 6/6 in log scale

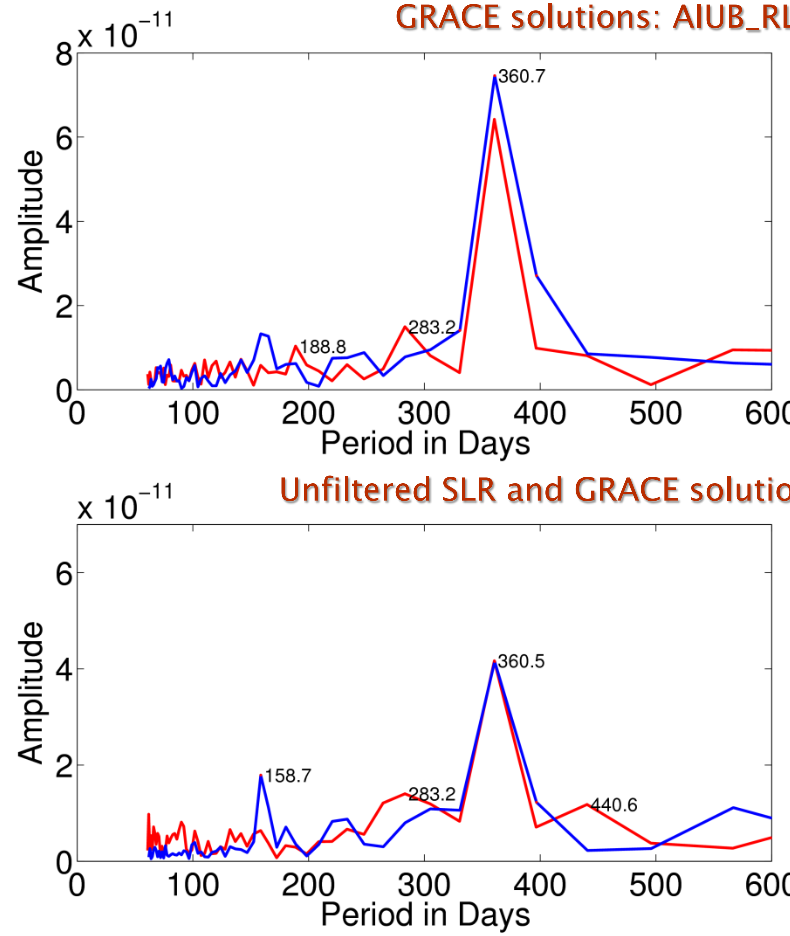
- LAGEOS-1/2 are very sensitive to degree 2 SH.
- LAGEOS sensitivity drops down for degrees higher than 4.
- LEOs are not very sensitive to even zonal coefficients (C20, C40, C60) due to short arcs (1-day) and estimated empirical orbit parameters.
- LARES remarkably contributes to degree 4 and 6.
- Contribution from Larets and Blits is small.

Comparison w.r.t. GRACE K-Band



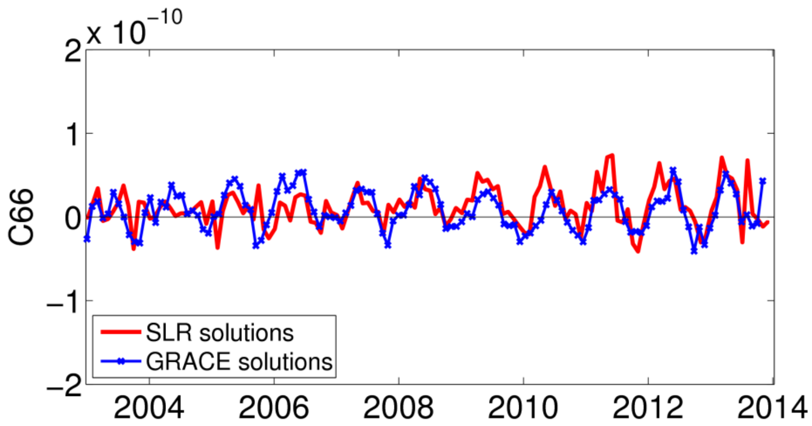
GRACE solutions: AIUB_RL02

Unfiltered SLR and GRACE solutions

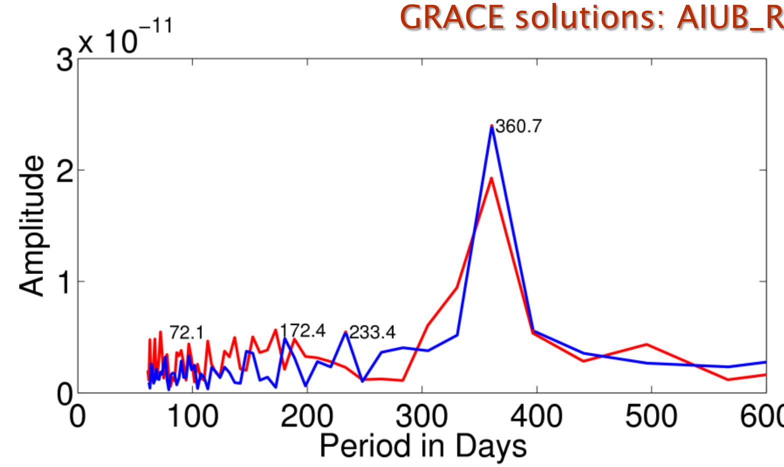


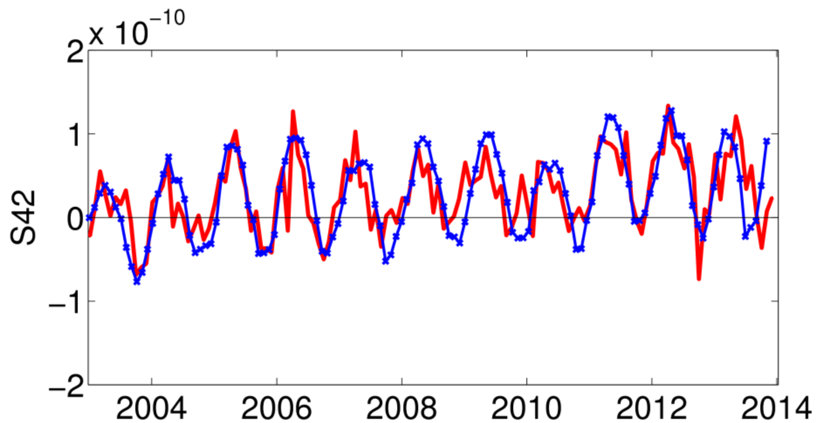
SLR and GRACE solutions agree very well, especially for sectorial and tesseral SH coefficients.

Comparison w.r.t. GRACE K-Band

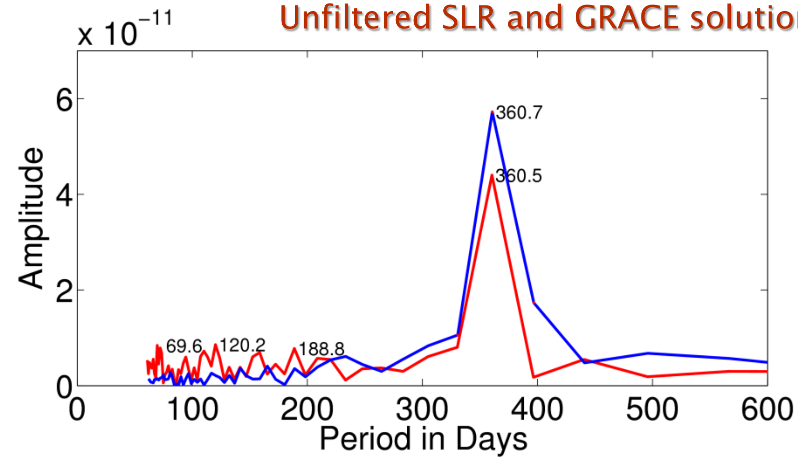


GRACE solutions: AIUB_RL02



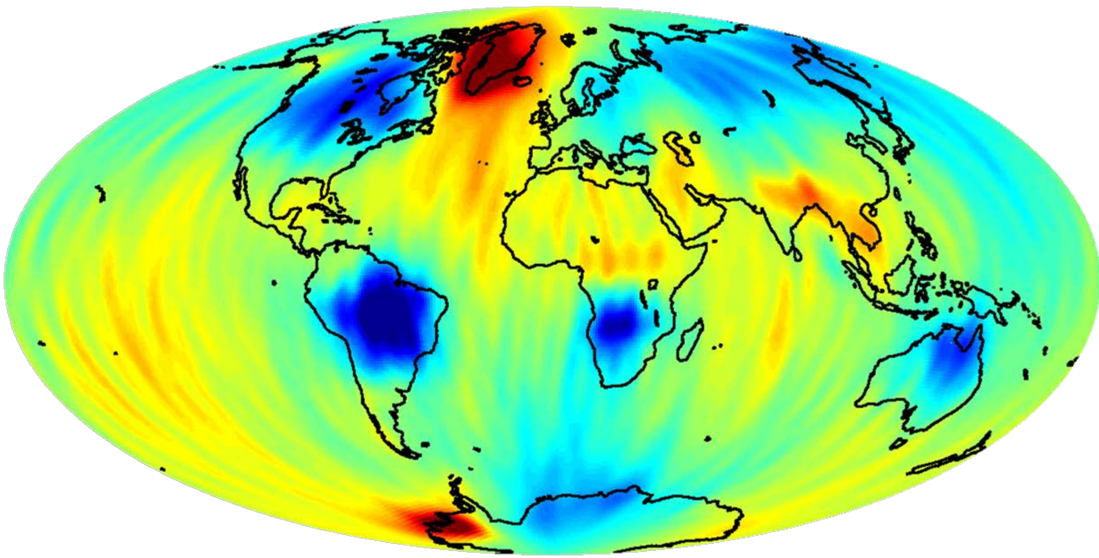


Unfiltered SLR and GRACE solutions

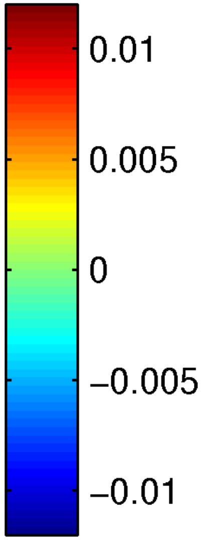


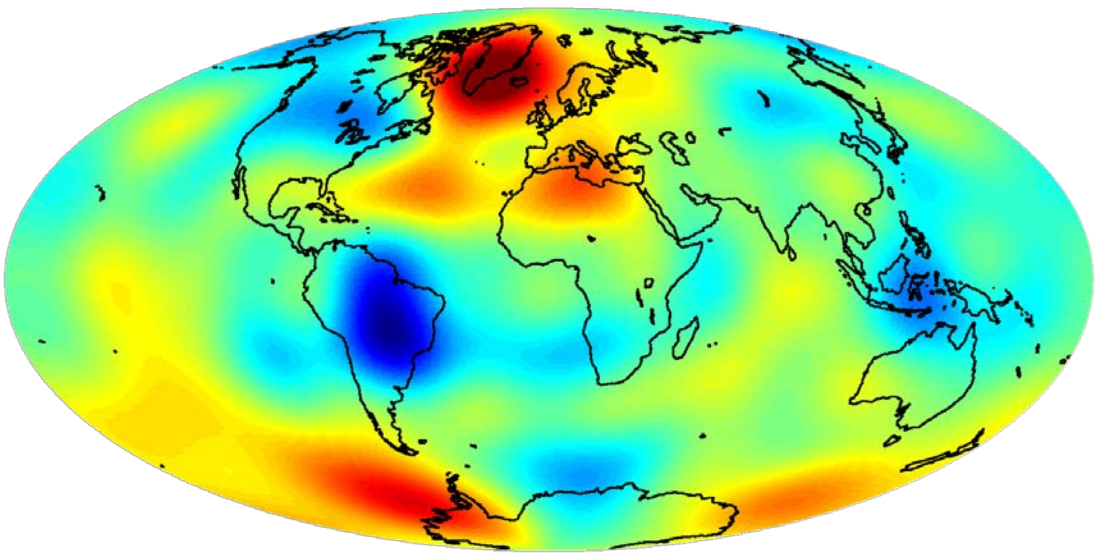
Even the coefficients of degree 6 can be still very well recovered by SLR.

SLR-only solutions



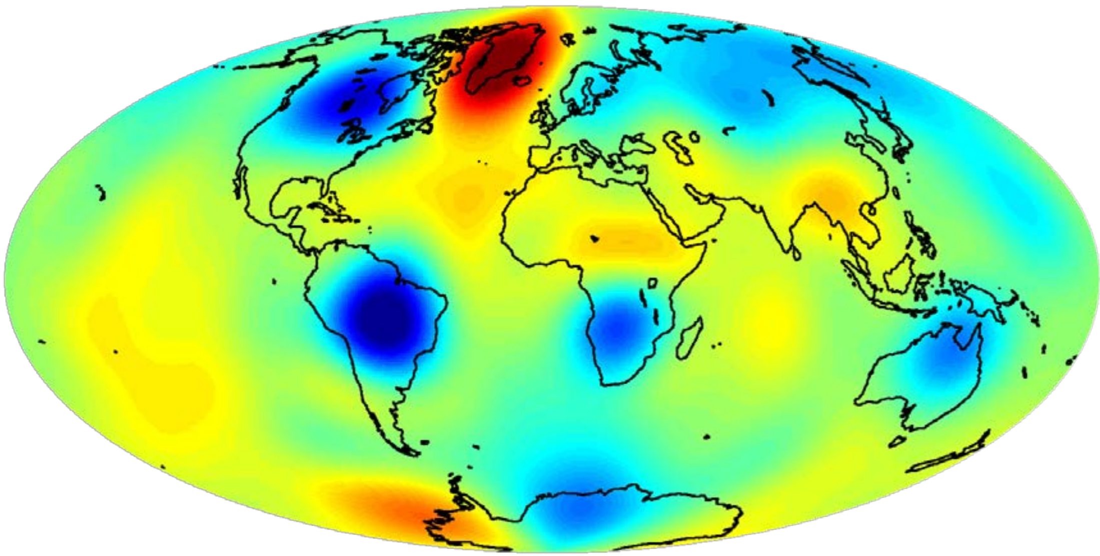
GRACE K-band solution
AIUB-RL02,
March 2011,
up to d/o 60/60
filtering 300 km





SLR-only solution,
March 2011,
up to d/o 10/10
no filtering

SLR-only solutions



GRACE K-band solution
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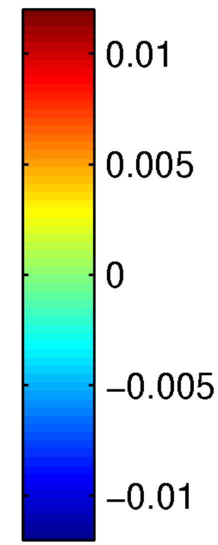
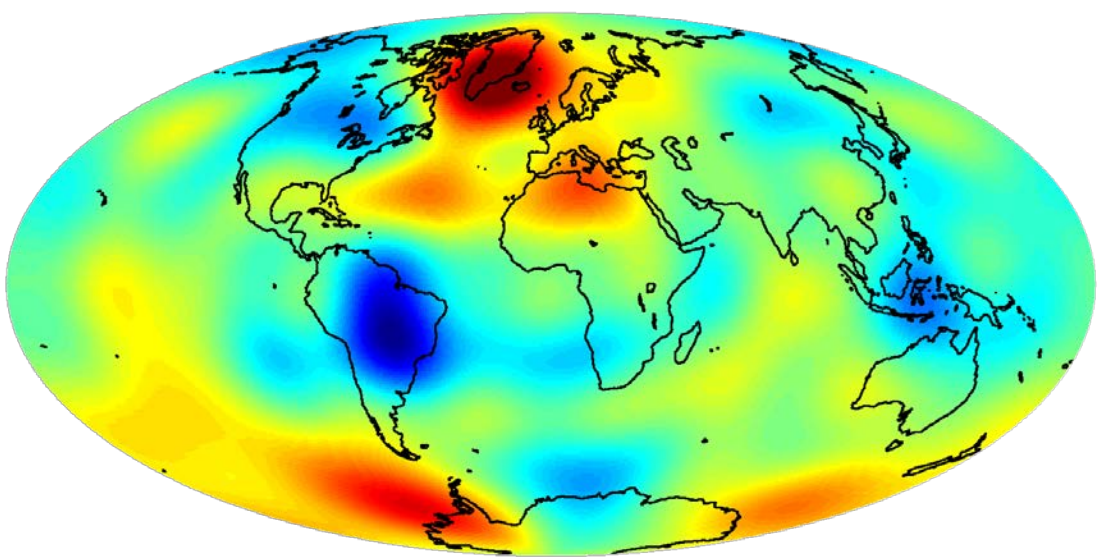
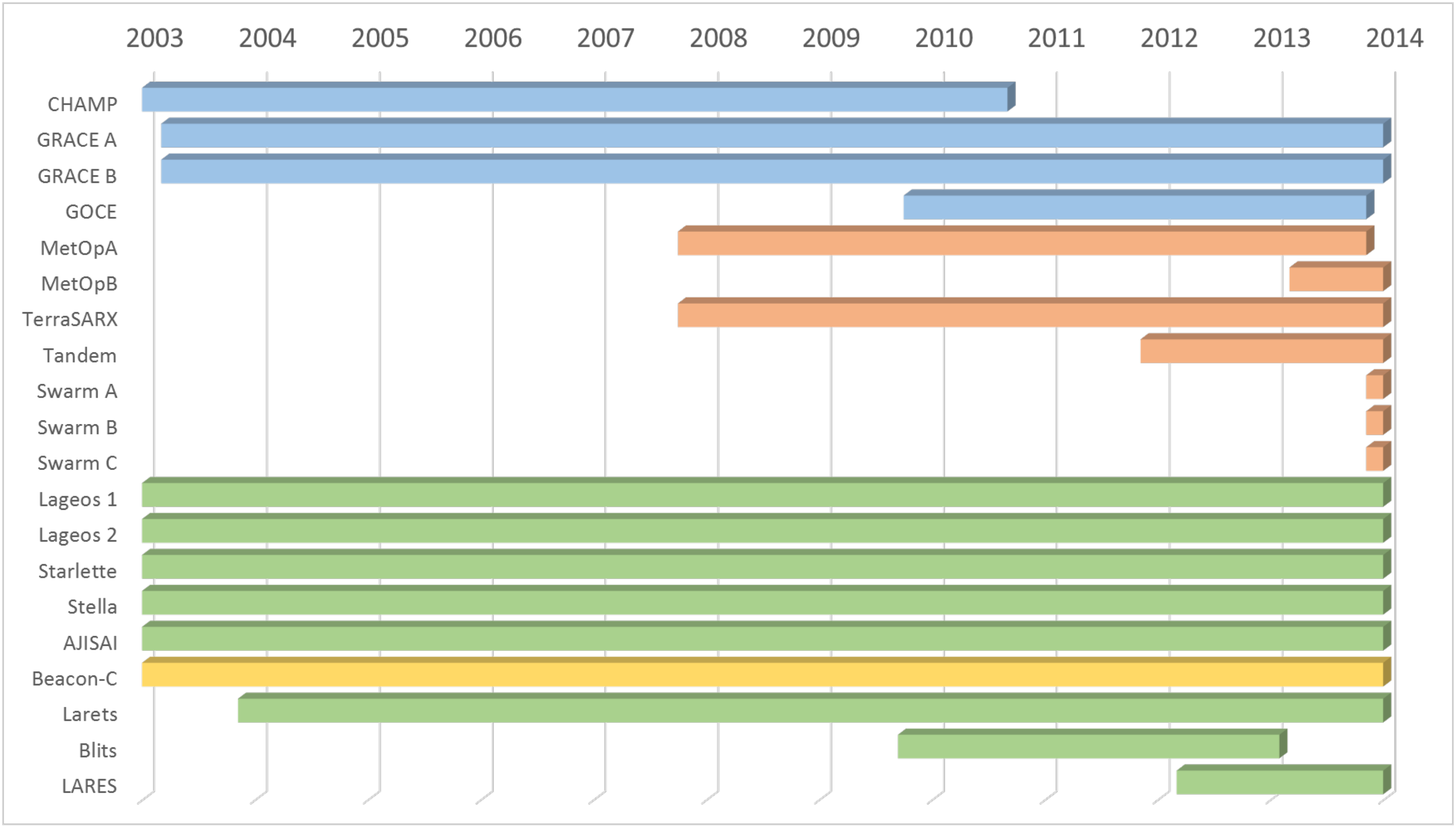


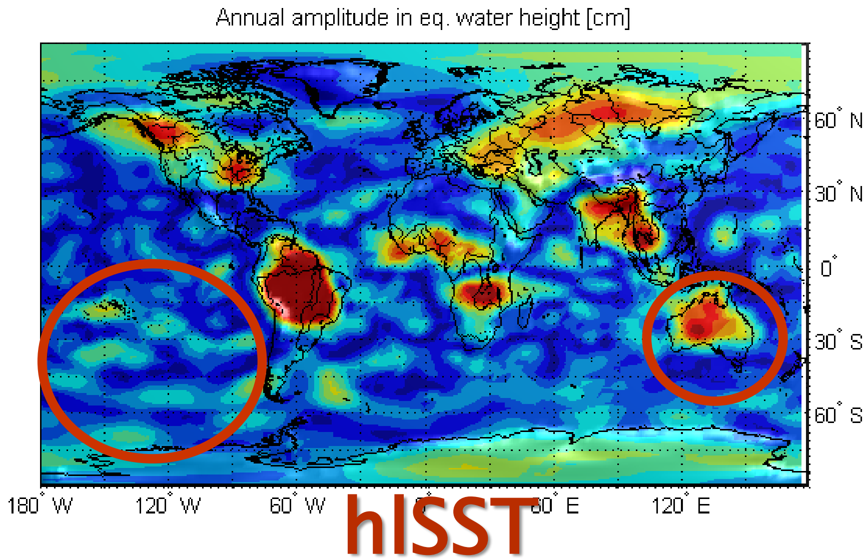


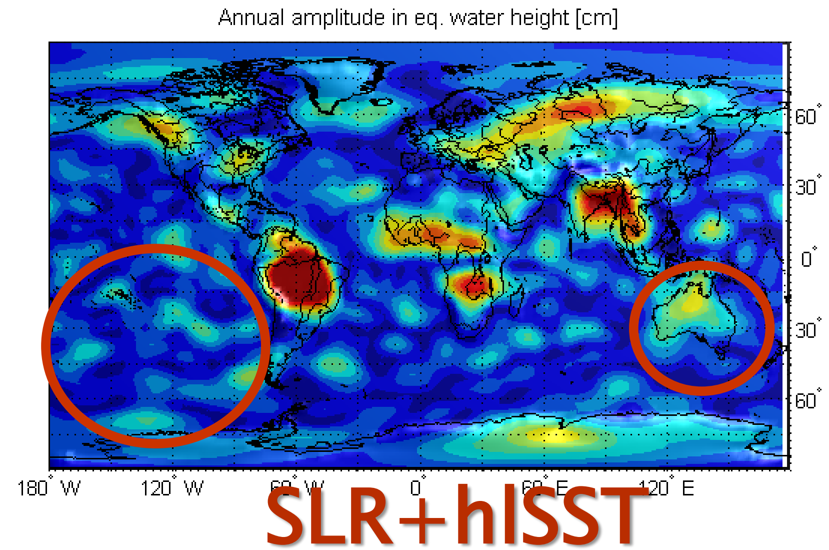
SLR-only solution,
March 2011,
up to d/o 10/10
no filtering

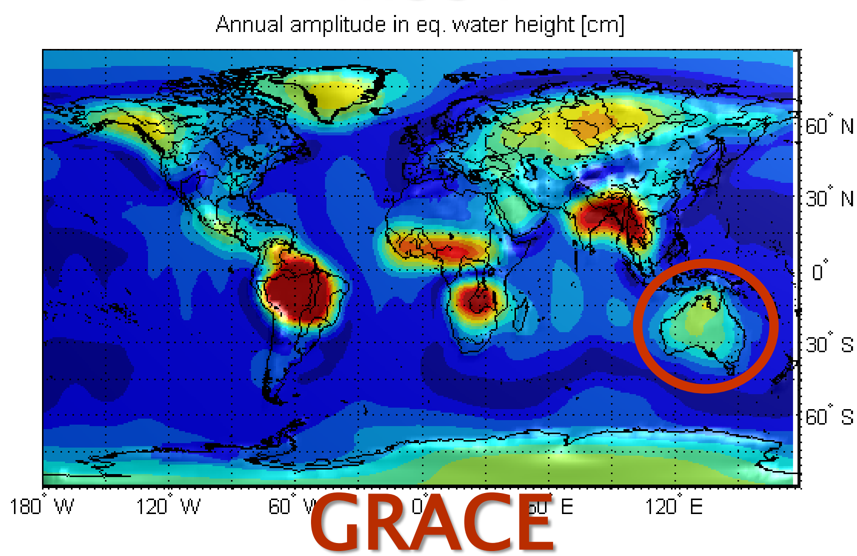
Combination of hlSST and SLR

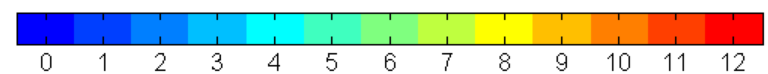


GRACE vs. hlSST vs. SLR+hlSST



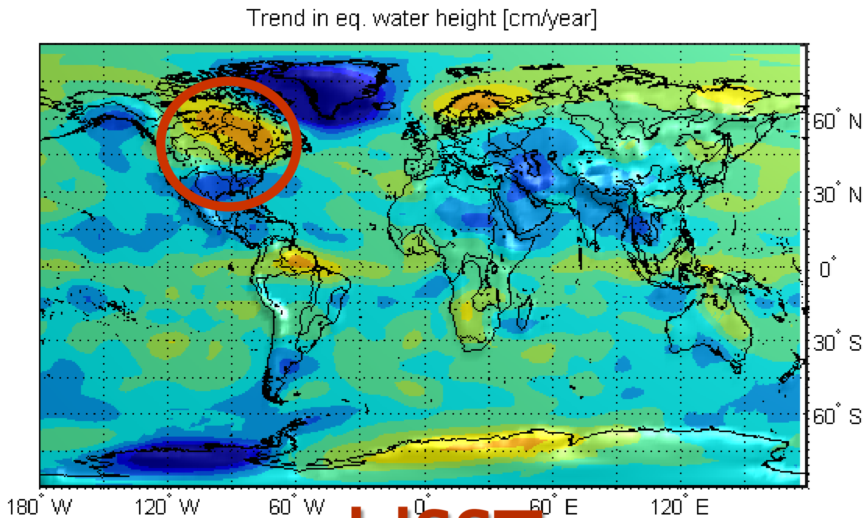




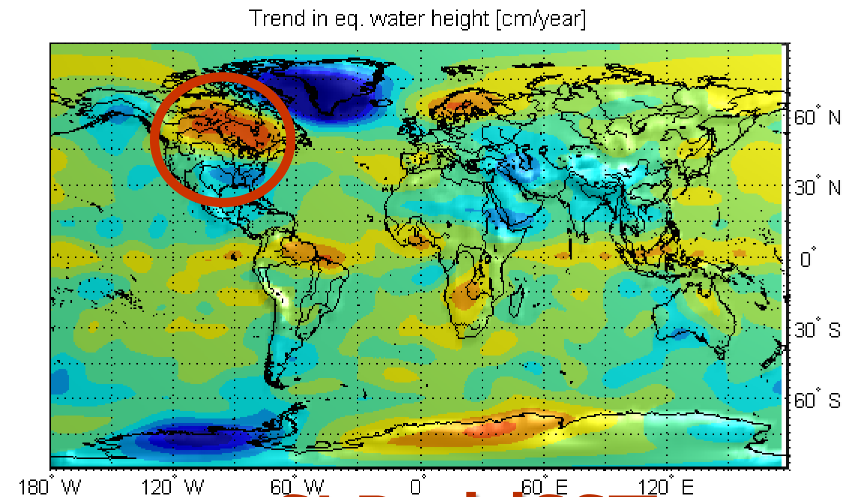


Combination of hlSST solutions with SLR reduces the variations over oceans and some spurious signals.

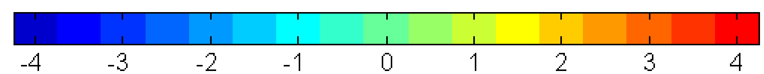
GRACE vs. hlSST vs. SLR+hlSST

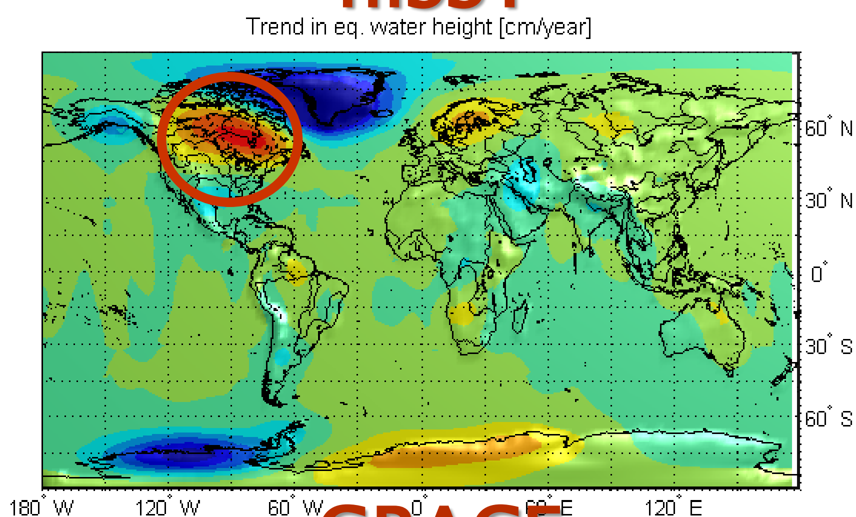


hlSST



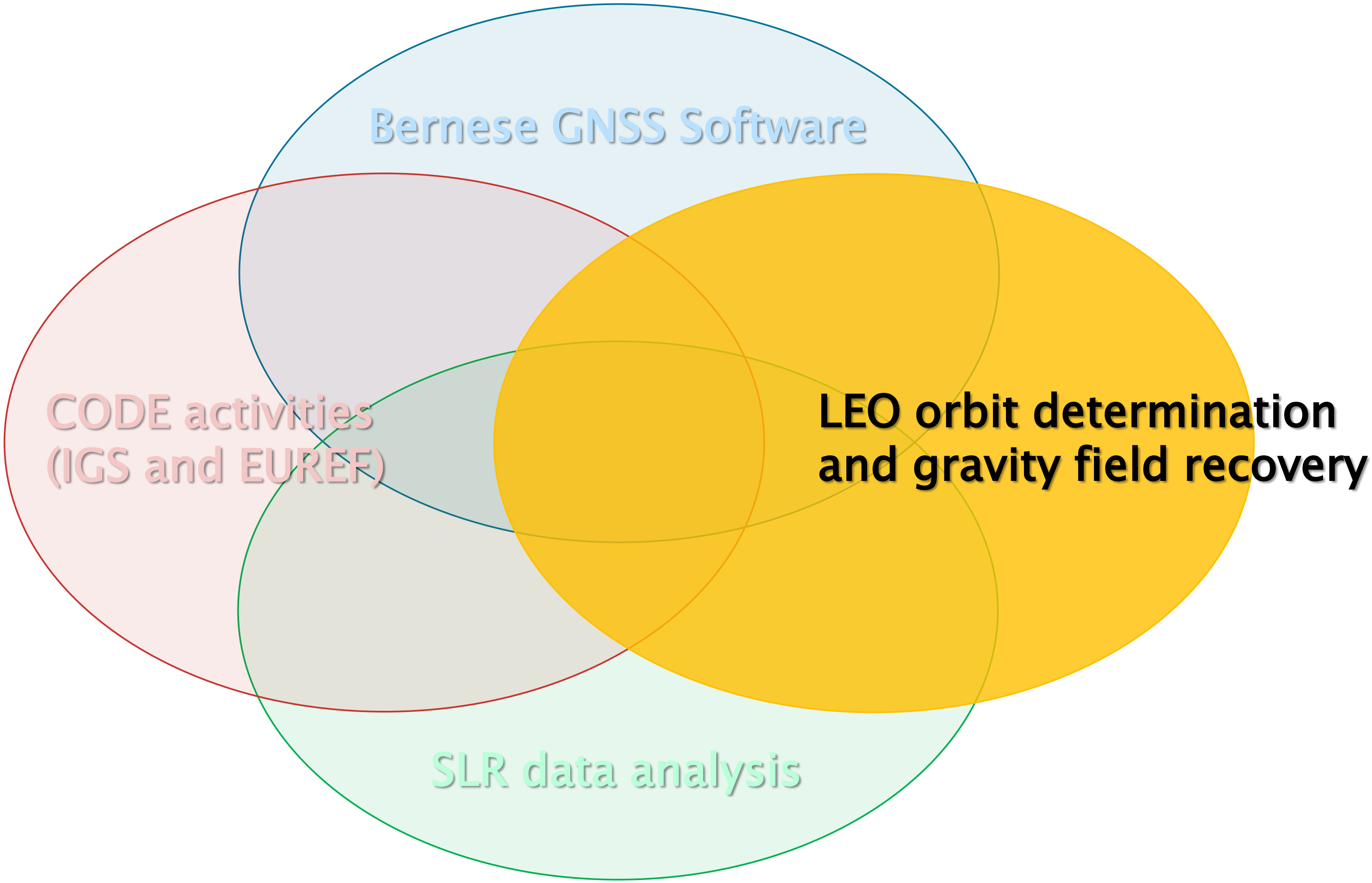
SLR+hlSST





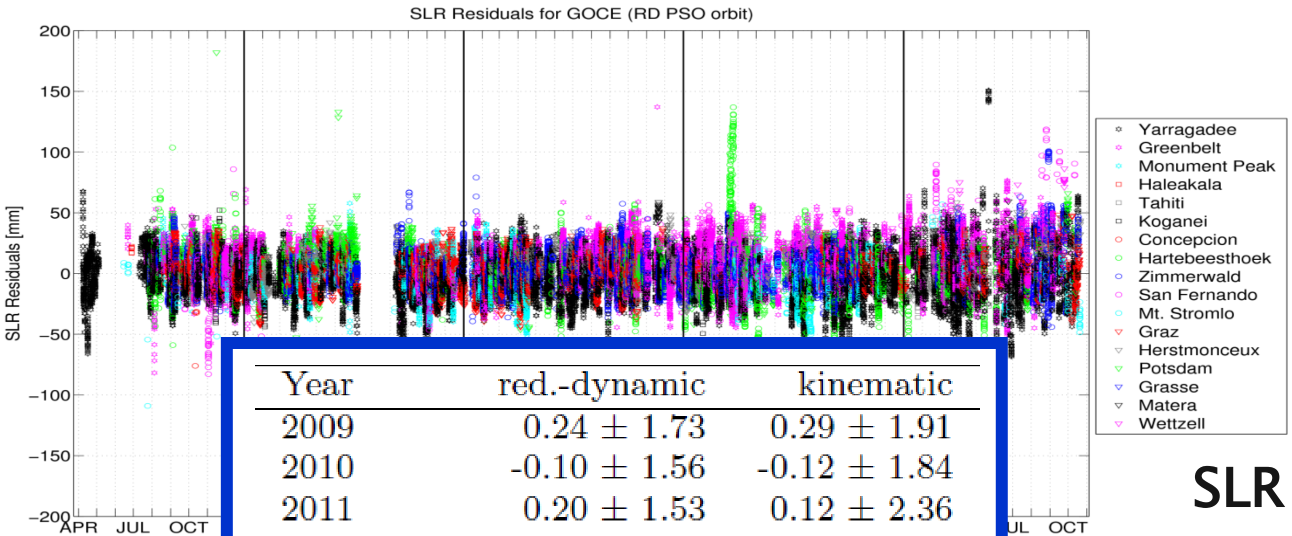
GRACE

Satellite Geodesy Research Group



GOCE-HPF:
Berechnung genauer Bahnen und Schwerefeldbestimmung

Orbit validation with SLR

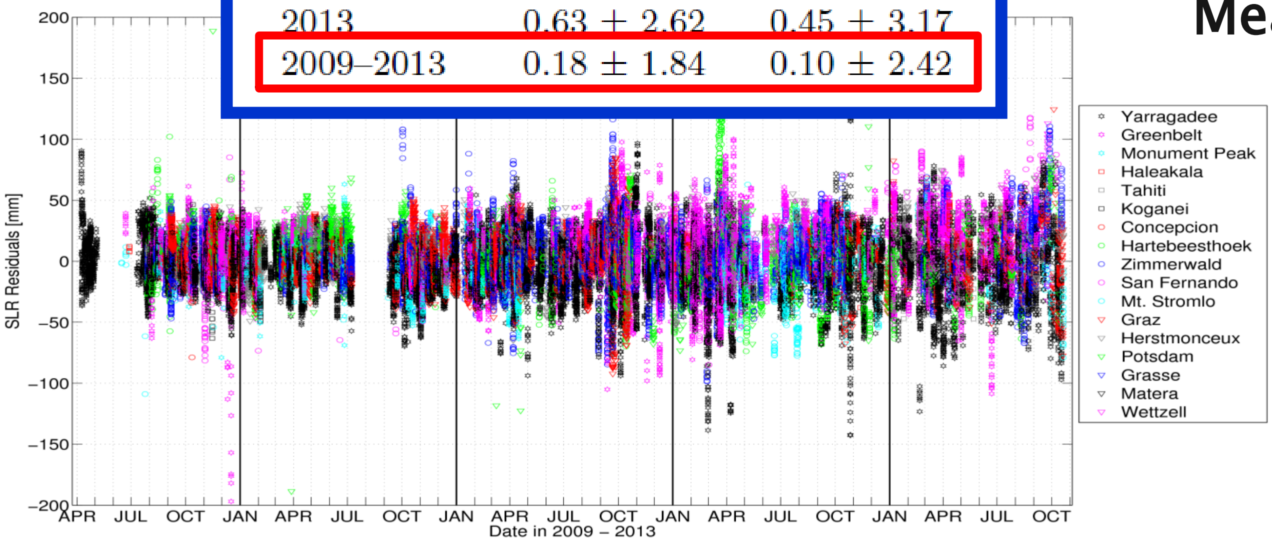


Reduced-dynamic

Year	red.-dynamic	kinematic
2009	0.24 ± 1.73	0.29 ± 1.91
2010	-0.10 ± 1.56	-0.12 ± 1.84
2011	0.20 ± 1.53	0.12 ± 2.36
2012	0.10 ± 1.94	-0.05 ± 2.78
2013	0.63 ± 2.62	0.45 ± 3.17
2009–2013	0.18 ± 1.84	0.10 ± 2.42

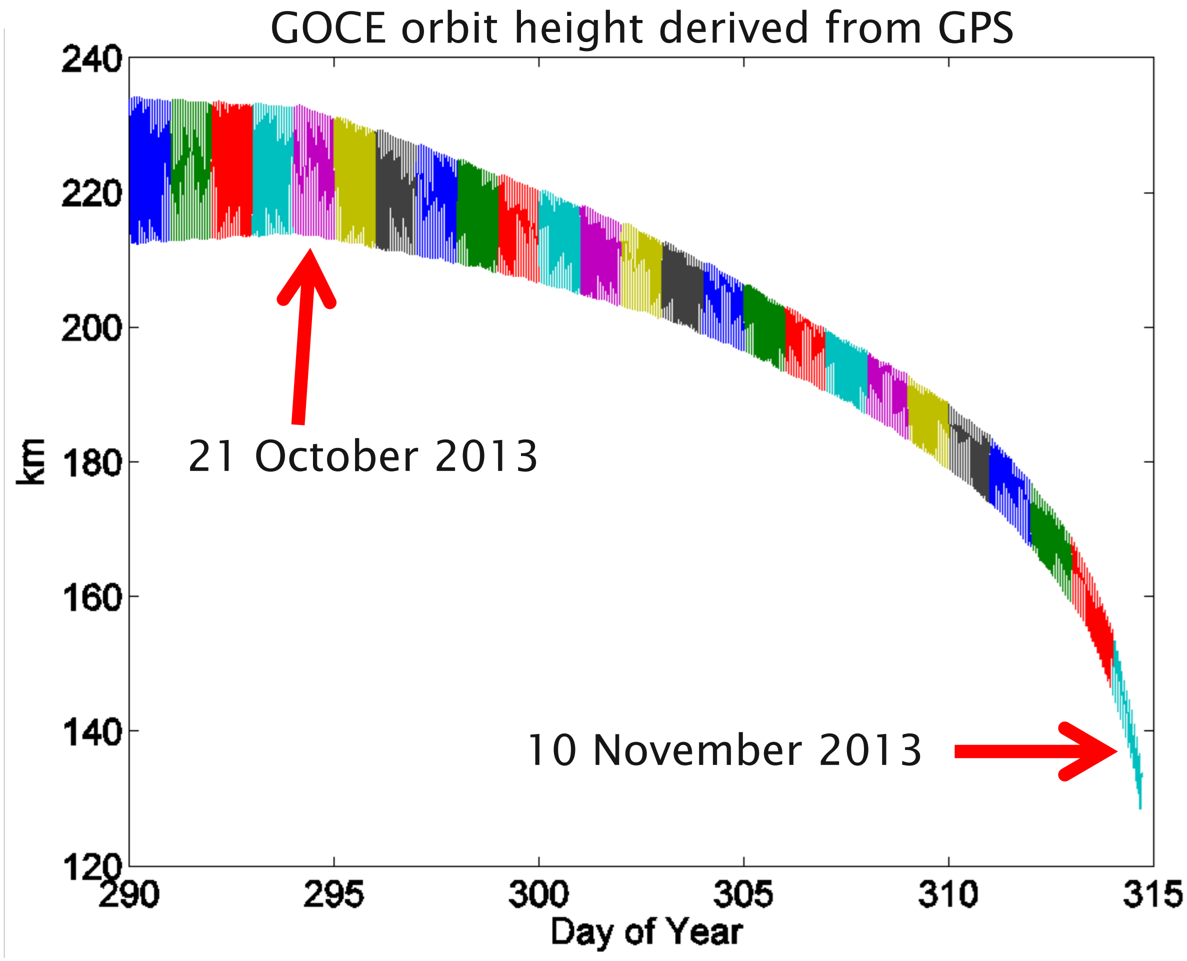
SLR statistics:

Mean ± RMS (cm)



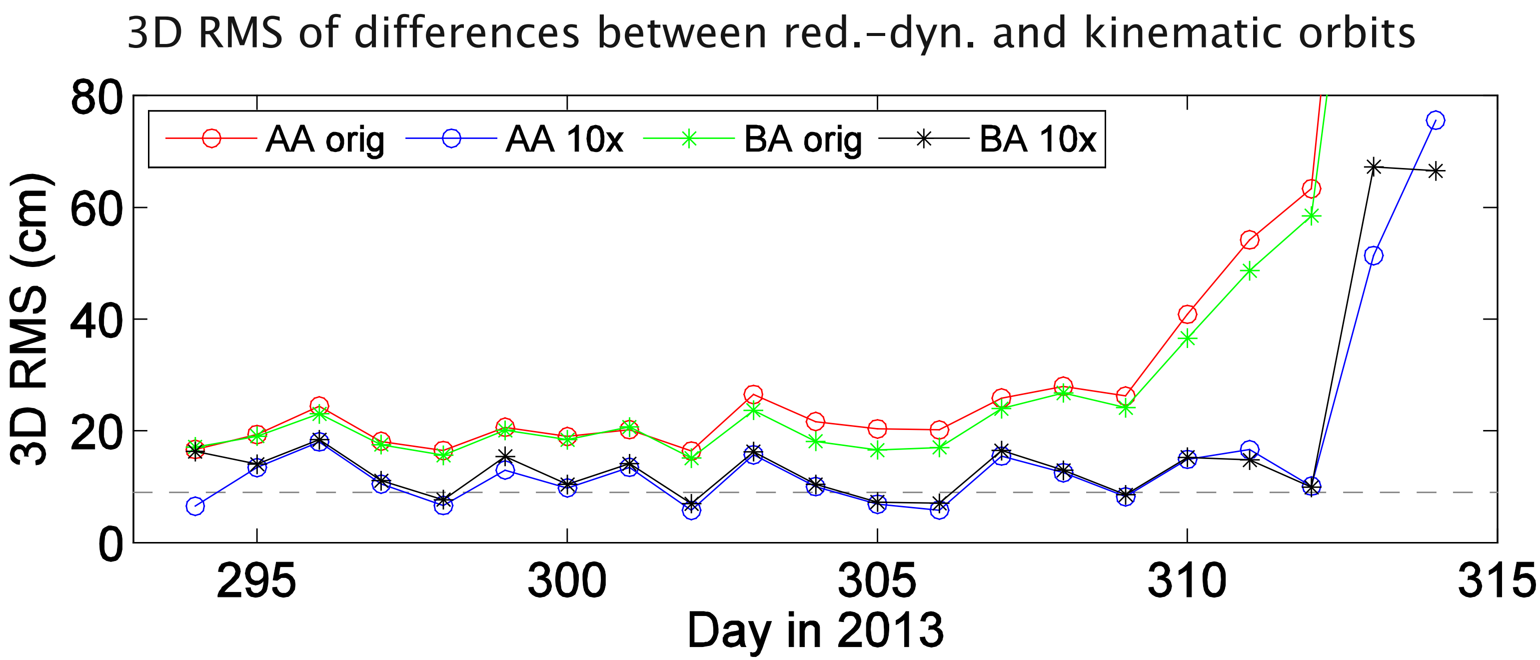
Kinematic

Last Days



- Last available GPS measurements: **10 November, 17:15:20 UTC**

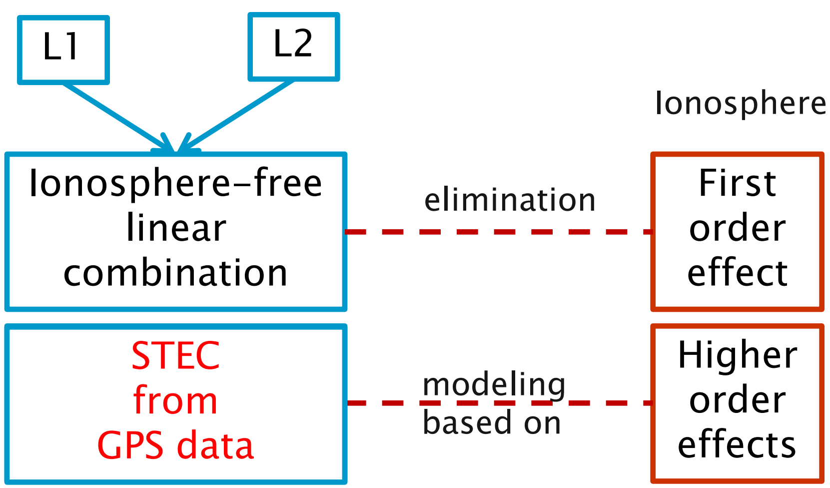
Last Days

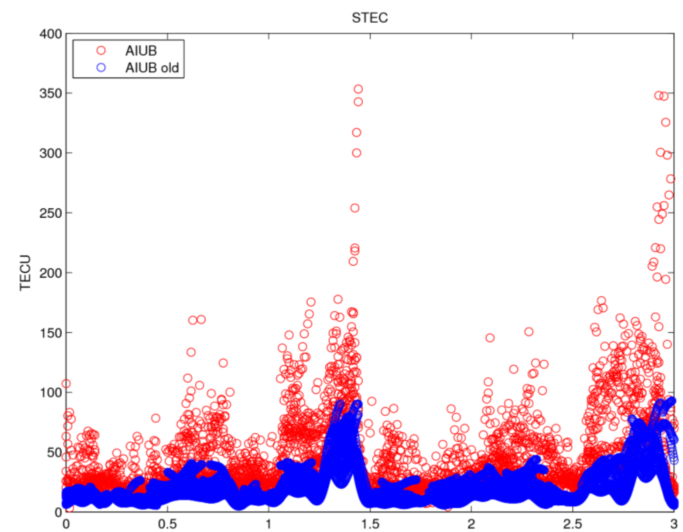


- If we look at the differences between the reduced-dynamic orbits from SSTI-B and the kinematic orbits from SSTI-A, the differences are very similar
  - Reason for this is the quality of the kinematic orbit, which is slightly better for SSTI-B because of less data gaps
  - The differences in the quality of the kinematic orbit are not critical for the validation of the reduced-dynamic orbit

Attempts to model the systematic effects

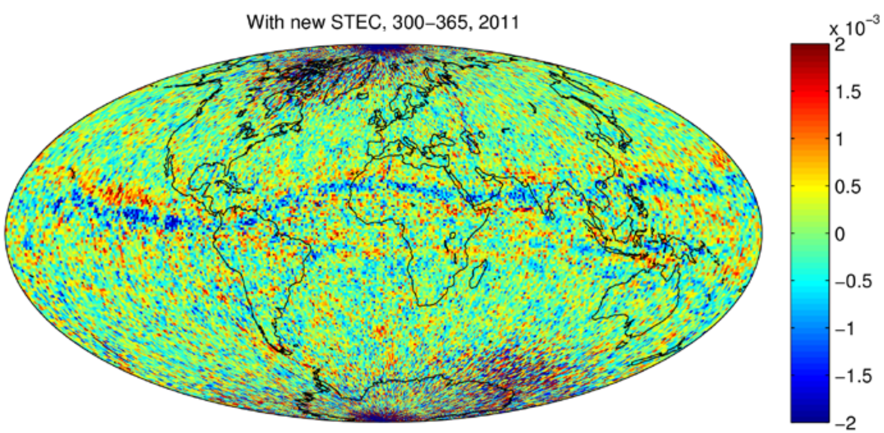
- Conventional modeling of HOI correction terms does not show any improvements. Also the application of further HOI correction terms than recommended by the IERS Conventions 2010 does not bring any further improvements.
- Ionosphere delays (= slant TEC) need to be directly derived from the geometry-free linear combination to compute more realistic HOI correction terms.



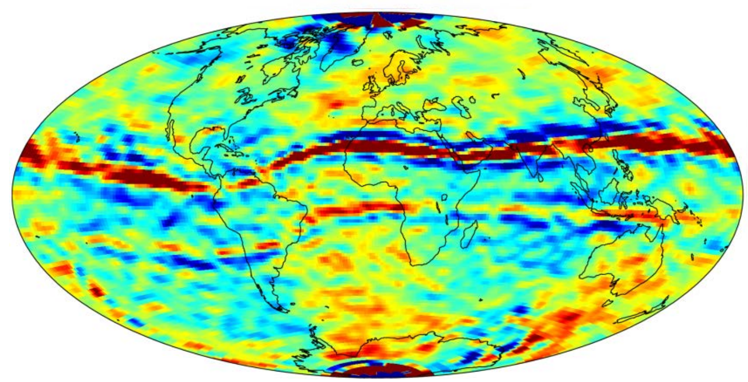


Attempts to model the systematic effects

- STEC estimations are fed into the kinematic orbit determination instead of the global ionosphere map
- HOI correction terms are computed based on the STEC estimations
- Only partial reduction achieved so far in gravity field solutions

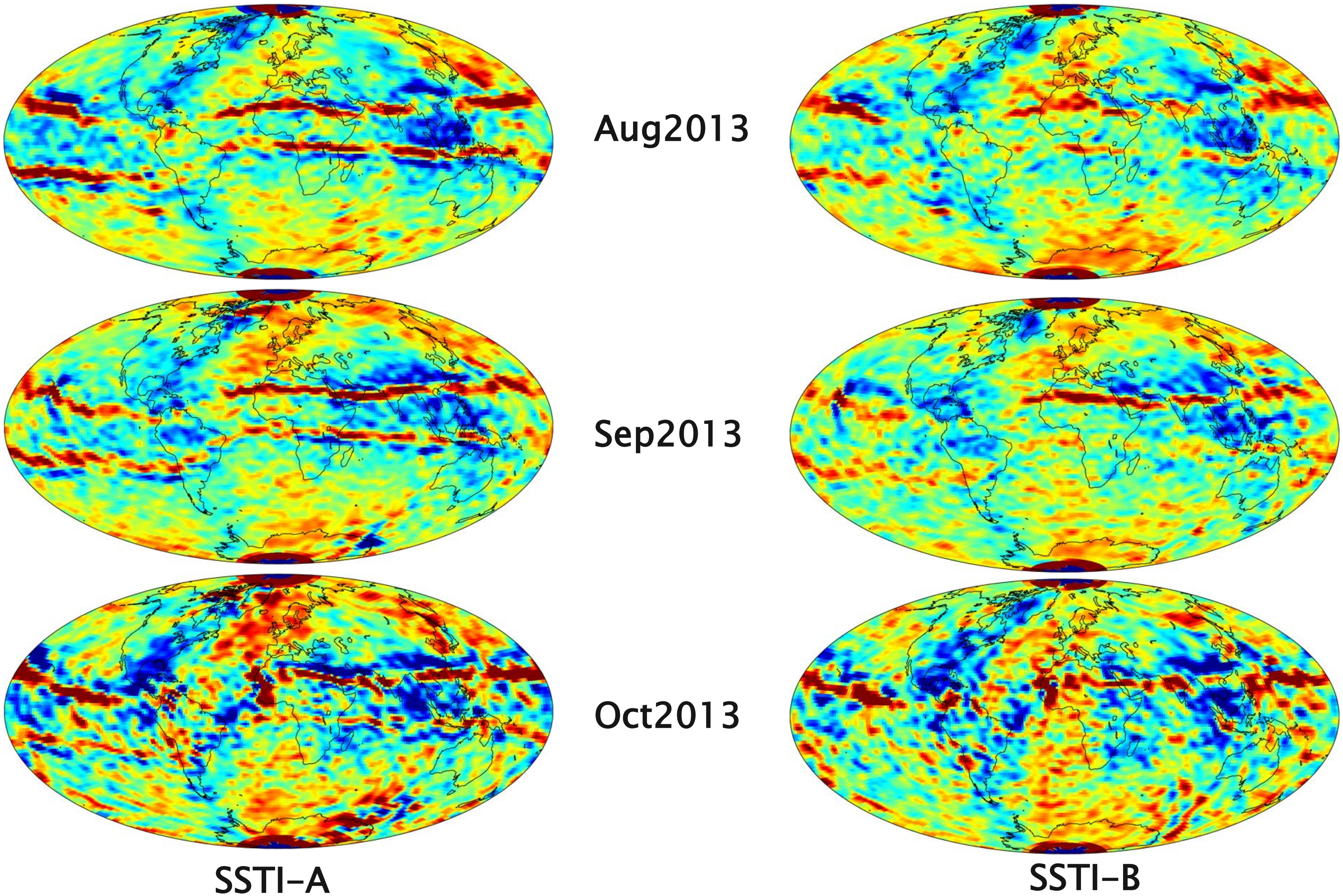


Phase observation residuals (– 2 mm … +2 mm) mapped to the ionosphere piercing point



Geoid height differences (–5 cm … 5 cm); Nov–Dec 2011

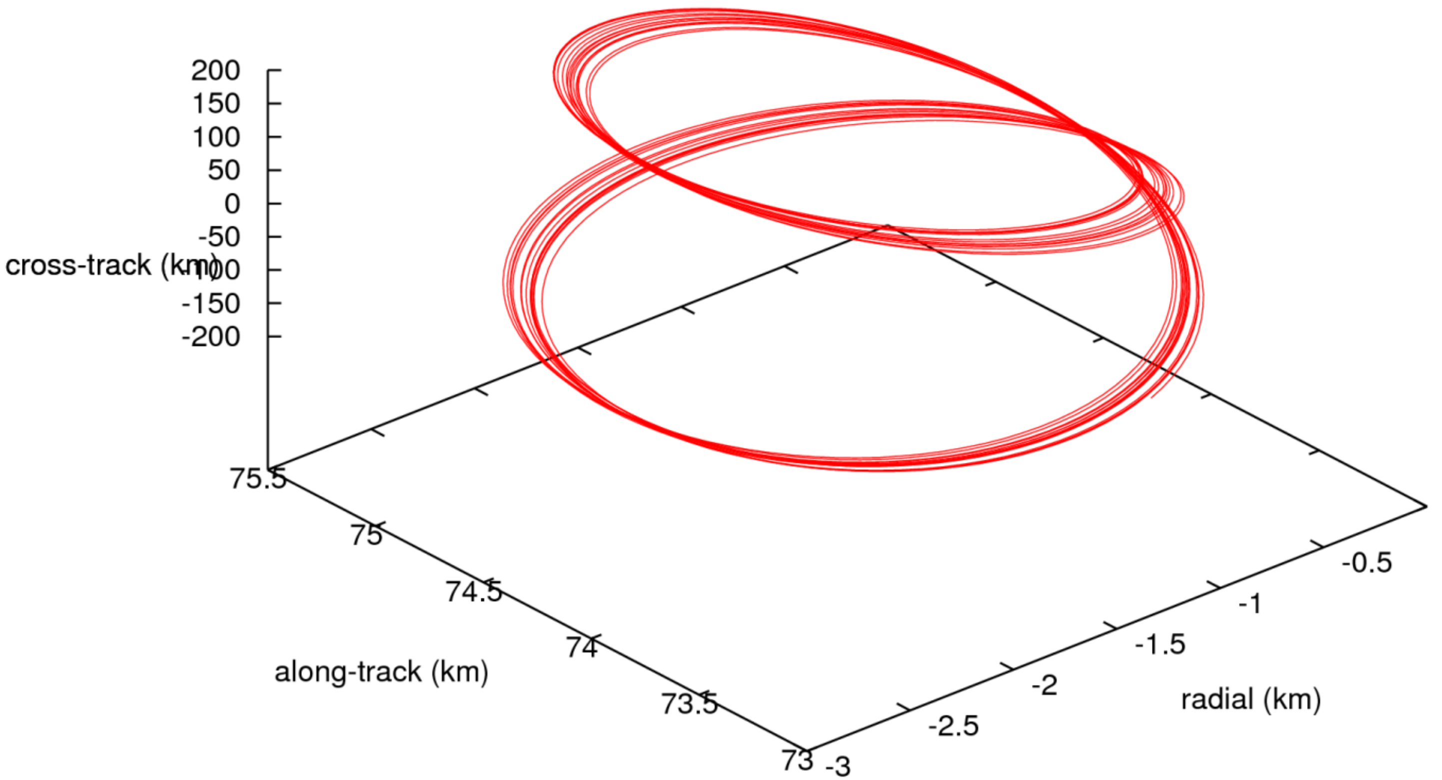
Solutions from different antennas



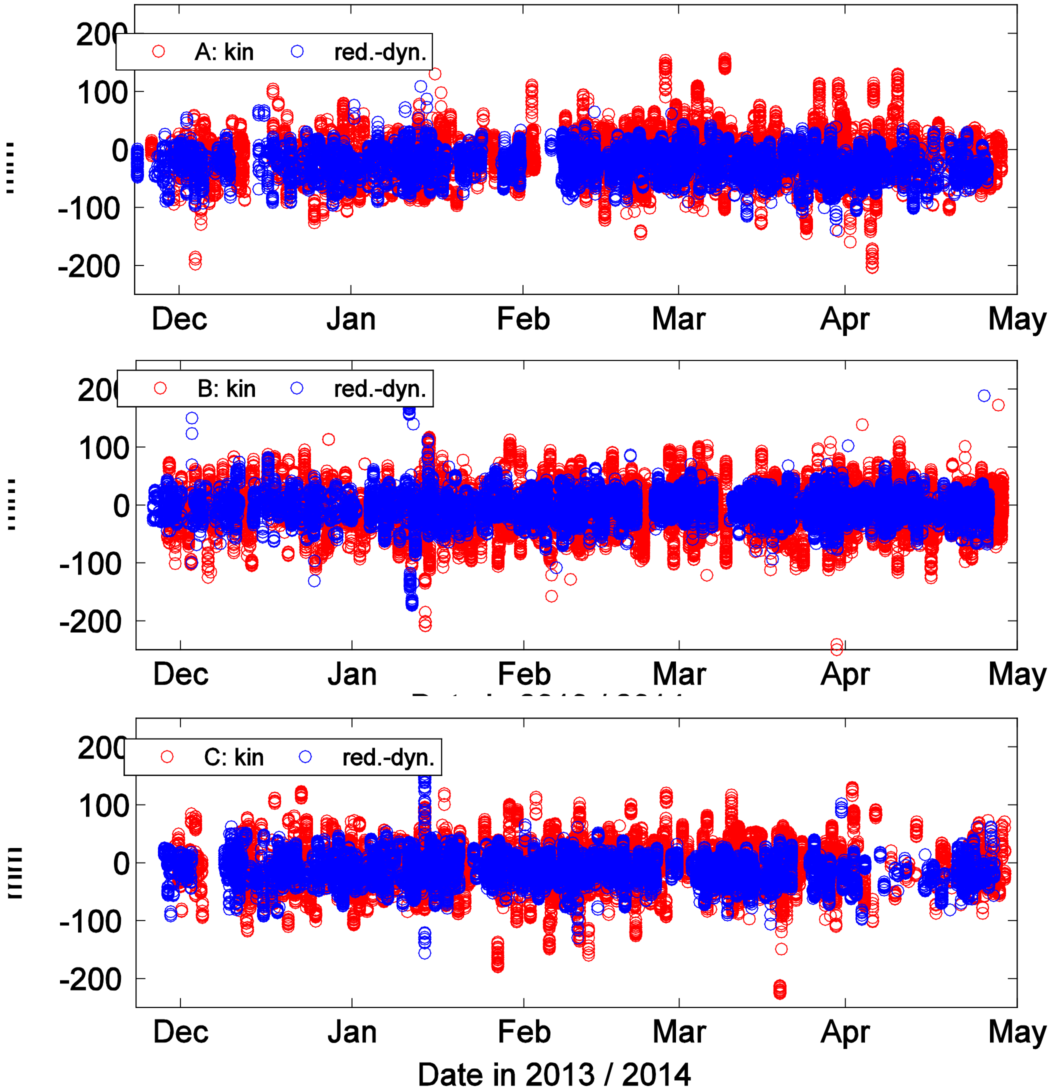
Swarm:
Berechnung genauer Bahnen und Schwerefeldbestimmung

Differences for Swarm: baseline geometry

- The baseline of GRACE is always in along-track direction
- The baseline of Swarm A & C is not “fixed” in one direction



Swarm Orbit validation



SLR validation:

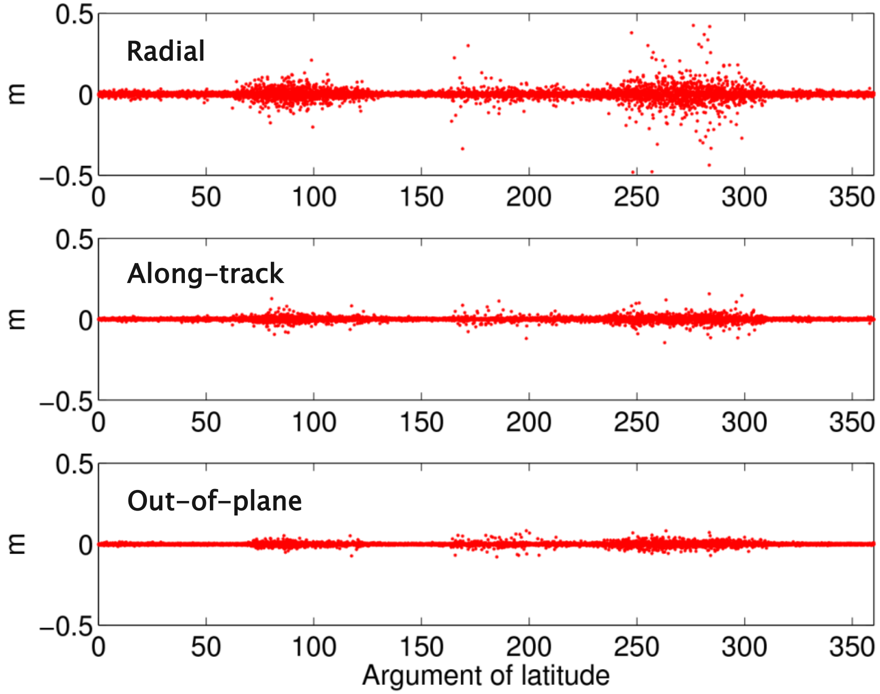
Mean ± RMS (cm)

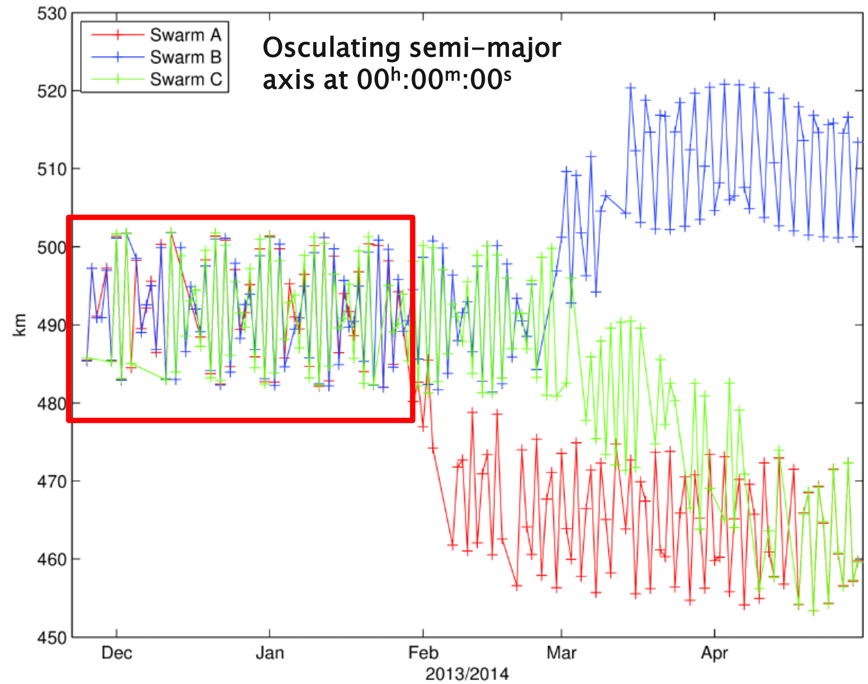
A: −0.35 ± 4.06
−0.08 ± 2.48

B: −0.73 ± 3.78
−0.26 ± 2.34

C: −0.38 ± 3.96
0.13 ± 2.34

Issues in Swarm kinematic positions





Similar to the GOCE mission, larger noise is also observed for kinematic positions over the polar regions and along the geomagnetic equator.

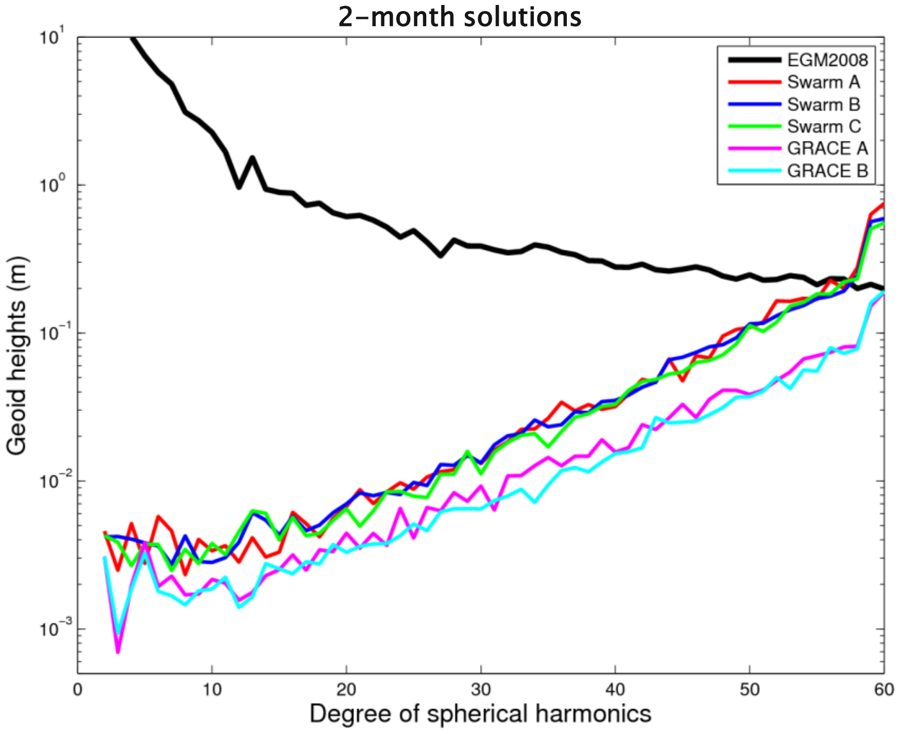
What are the consequences for gravity field determination?

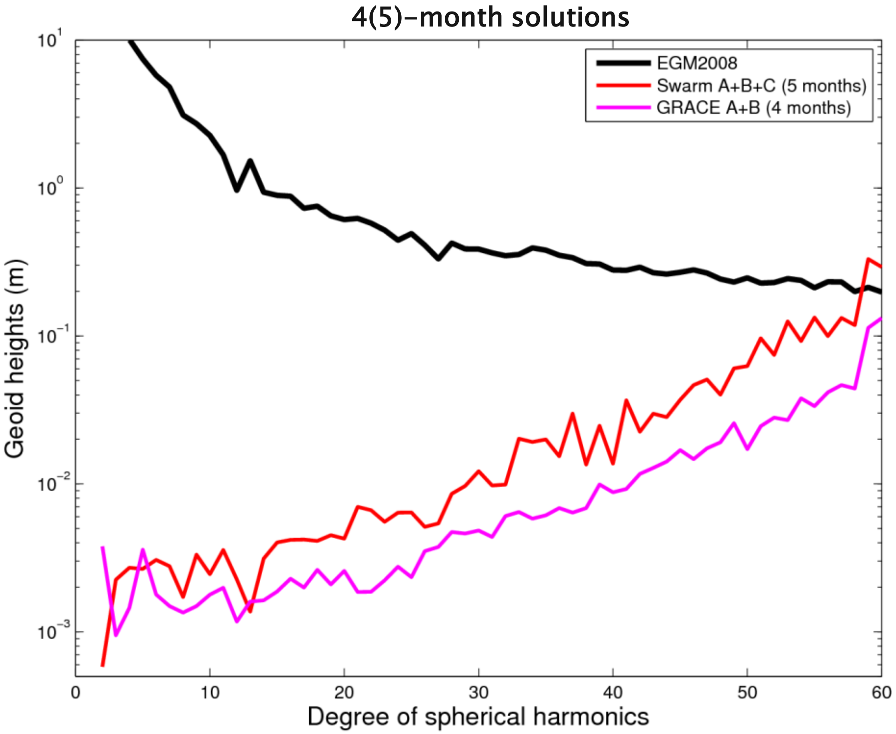
Based on the Swarm orbit configuration two test periods are selected for gravity field tests based on kinematic positions:

1 Dec 2013 – 31 Jan 2014 (2 months)

1 Dec 2013 – 31 Apr 2014 (5 months)

First Swarm gravity field solutions





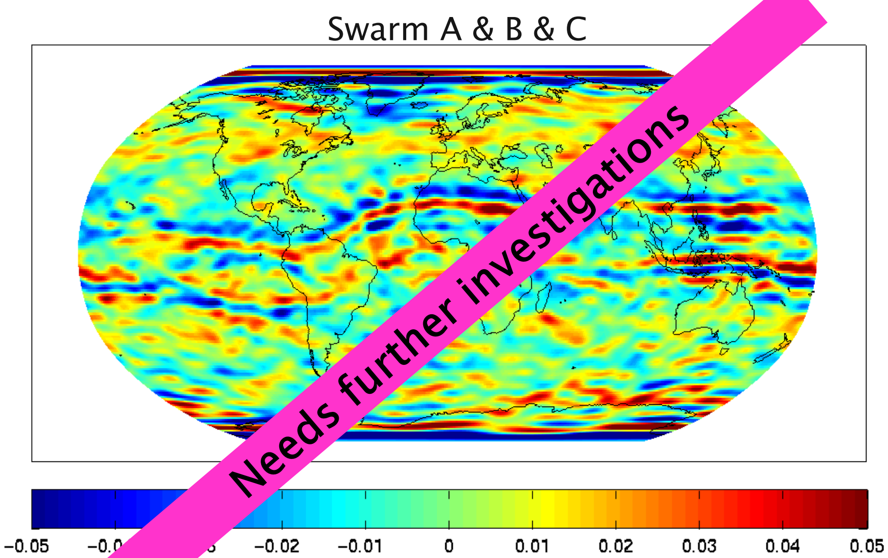
Individual 2-month solutions based on kinematic positions show a comparable quality for all three Swarm satellites.

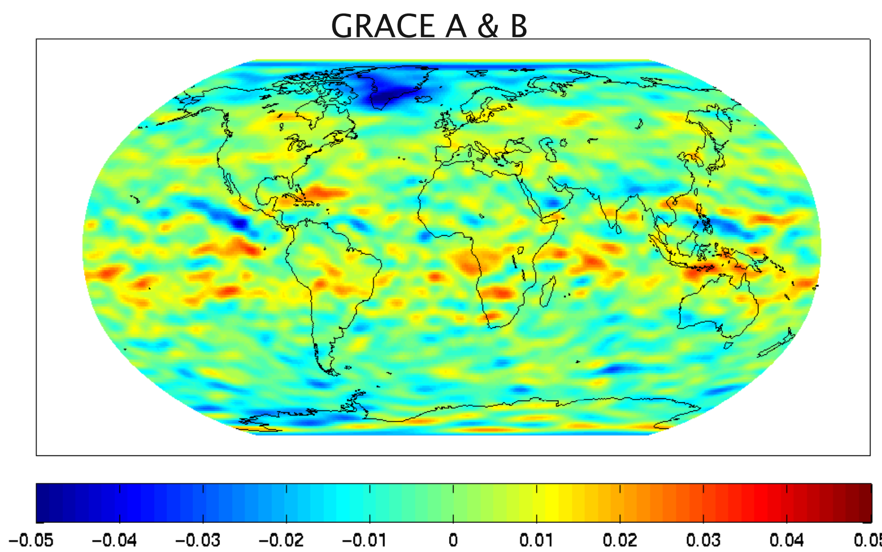
The performance is significantly worse than for GRACE solutions based on kinematic positions.

Combined Swarm A+B+C over longer time intervals are also significantly worse than GRACE A+B solutions.

Some improvement for degree 2 is observed.

Comparison of Swarm and GRACE solutions



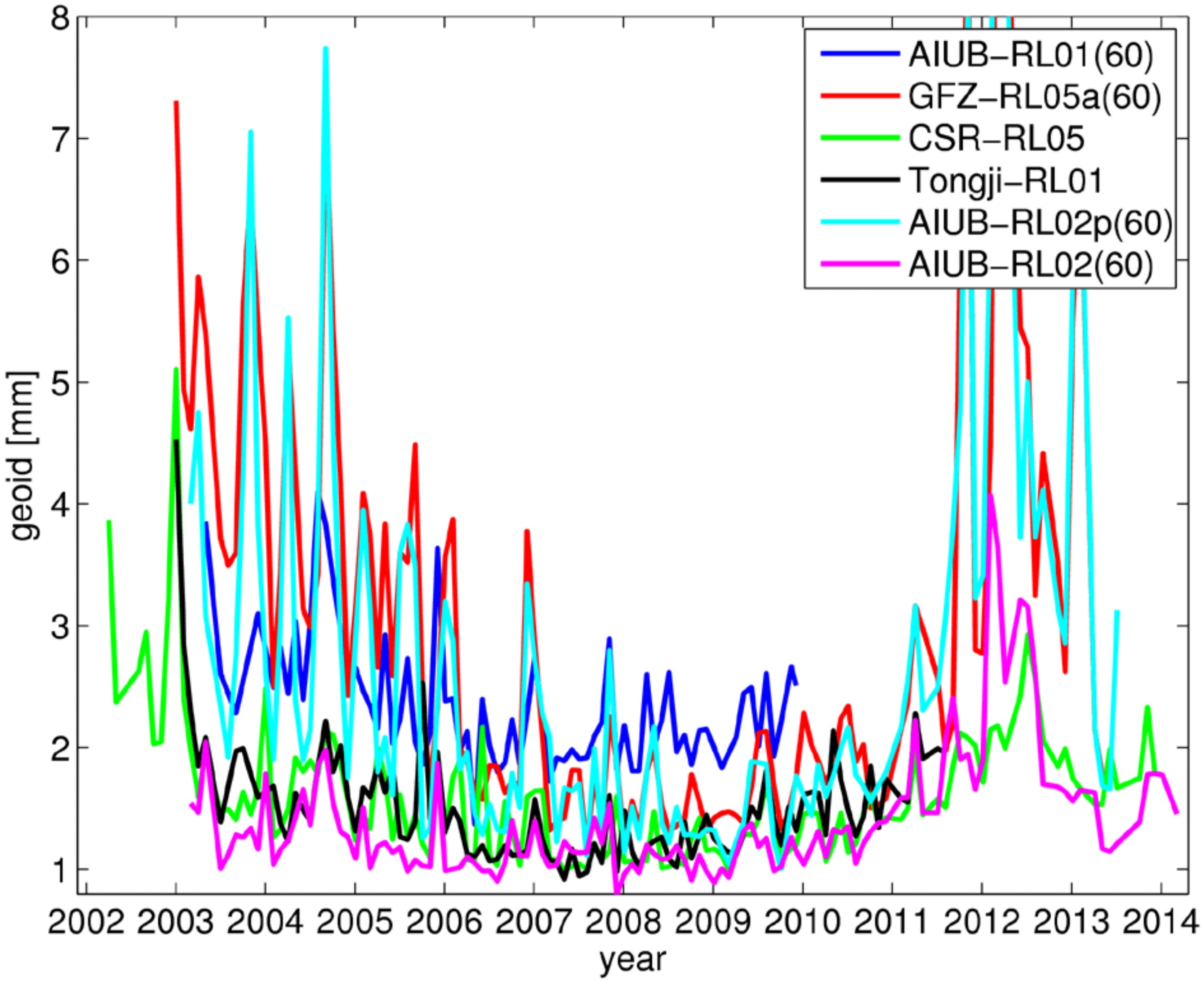


Differences between the solutions:

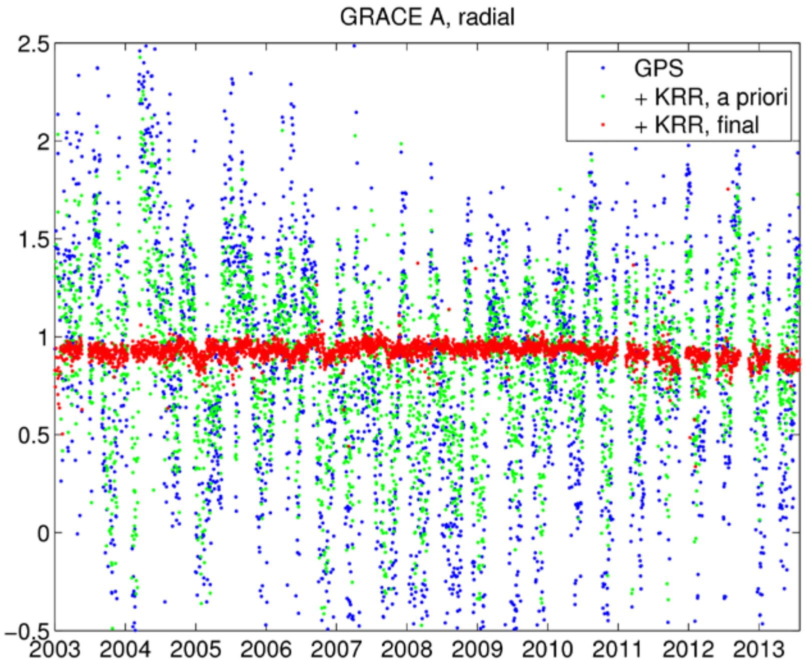
- Swarm 3 satellites, GRACE 2 satellites
- Swarm satellites are on higher altitude
- Swarm kinematic orbits are of worse quality
  - Swarm tracks max. 8 satellites, GRACE max. 10
  - Swarm has tracking problems over the pole and around the geomagnetic equator
  - Elevation cut-off: Swarm 10 degrees, GRACE 0 degrees
  - GRACE provides L1C, which has lower noise than L1P
- Different inclinations 87 ⇔ 89 degrees

Schwerefeldbestimmung mit GRACE

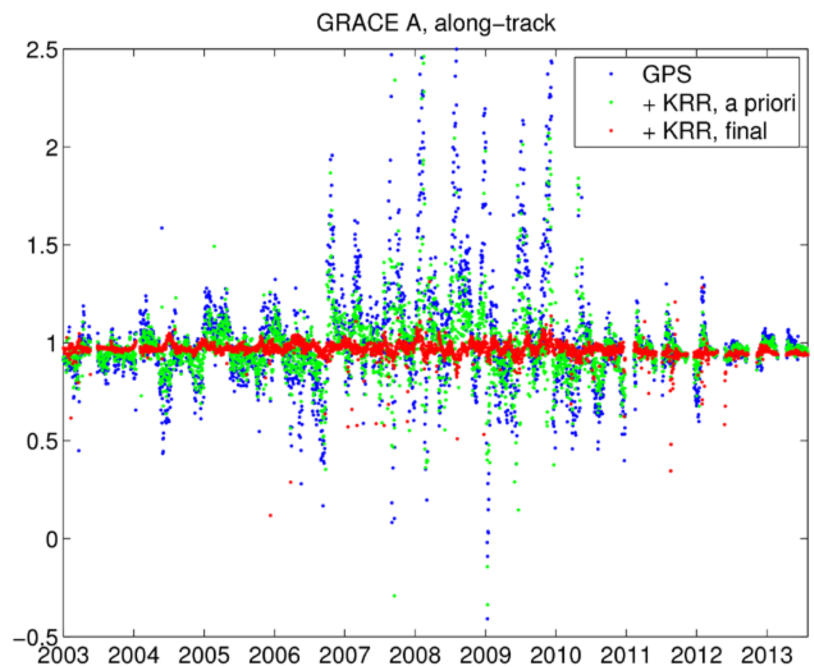
Noise (wSTD over oceans)



Daily ACC scale factors

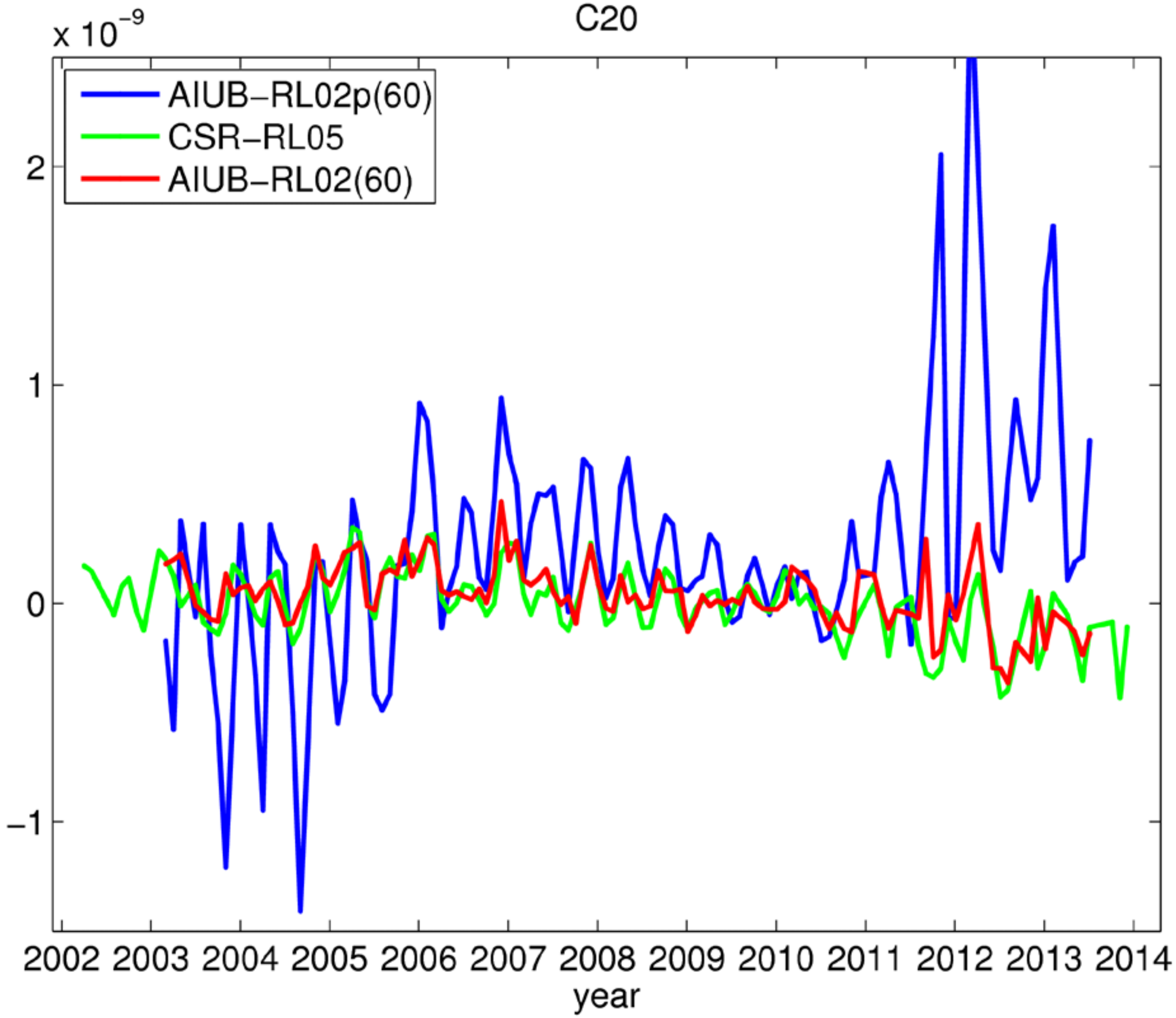


KRR enables a stable estimation of ACC scale- factors in radial and along-track.



The along-track ACC scale-factors are estimated more stable during times of high solar activity.

C20 without /with daily ACC-Scales



EGSIEM: Ein neues H2020 Projekt

EGSIEM project overview

A proposal for the project

EGSIEM European Gravity Service for Improved Emergency Management

has been submitted this spring to the EO-1 Space Call of the Horizon 2020 Framework Program for Research and Innovation.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE
Directorate H - Institute for Environment and Sustainability
Climate Risk Management

EGSIEM project overview

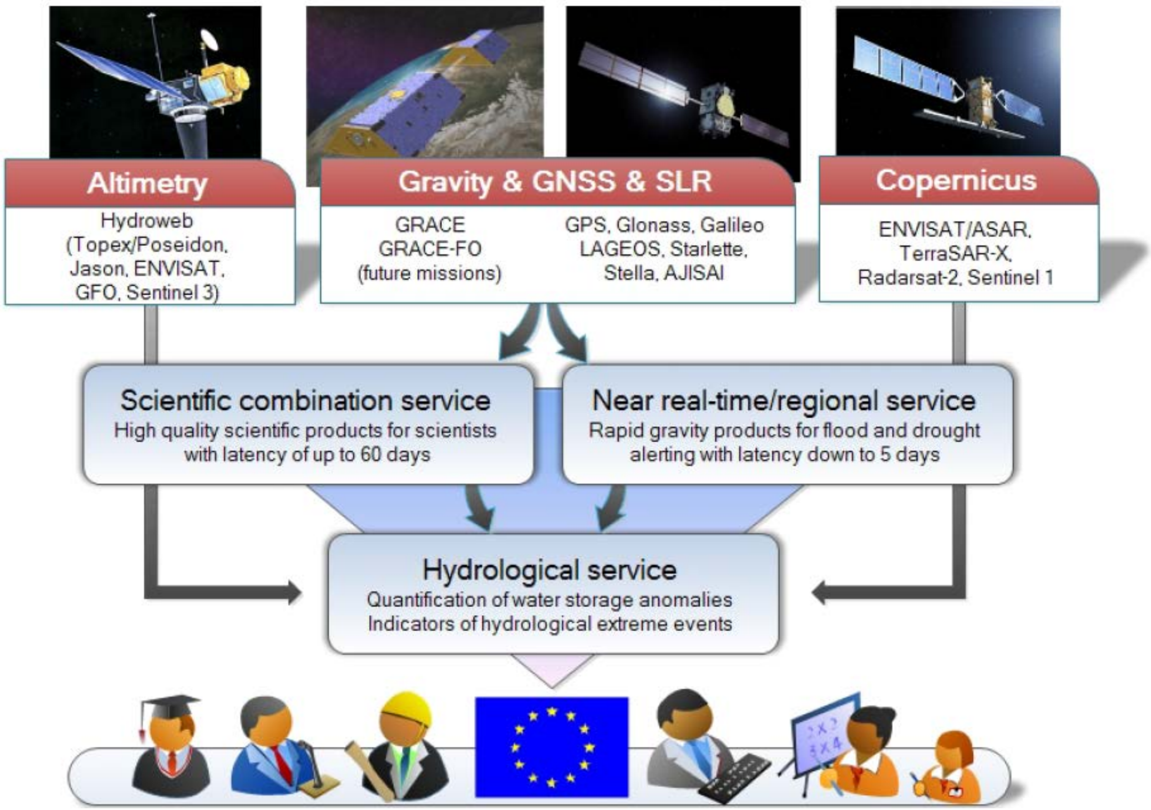
Currently EGSIEM is in the process of Grant Preparation with the European Commission. The project start is scheduled for January 1, 2015.

The three main objectives of EGSIEM are to

- **deliver the best gravity products for applications in Earth and environmental science research**
- **reduce the latency and increase the temporal resolution of the gravity and therefore mass redistribution products**
- **develop gravity-based indicators for extreme hydrological events and demonstrate their value for flood and drought forecasting and monitoring services**

EGSIEM project overview

- **Three dedicated services shall be established**



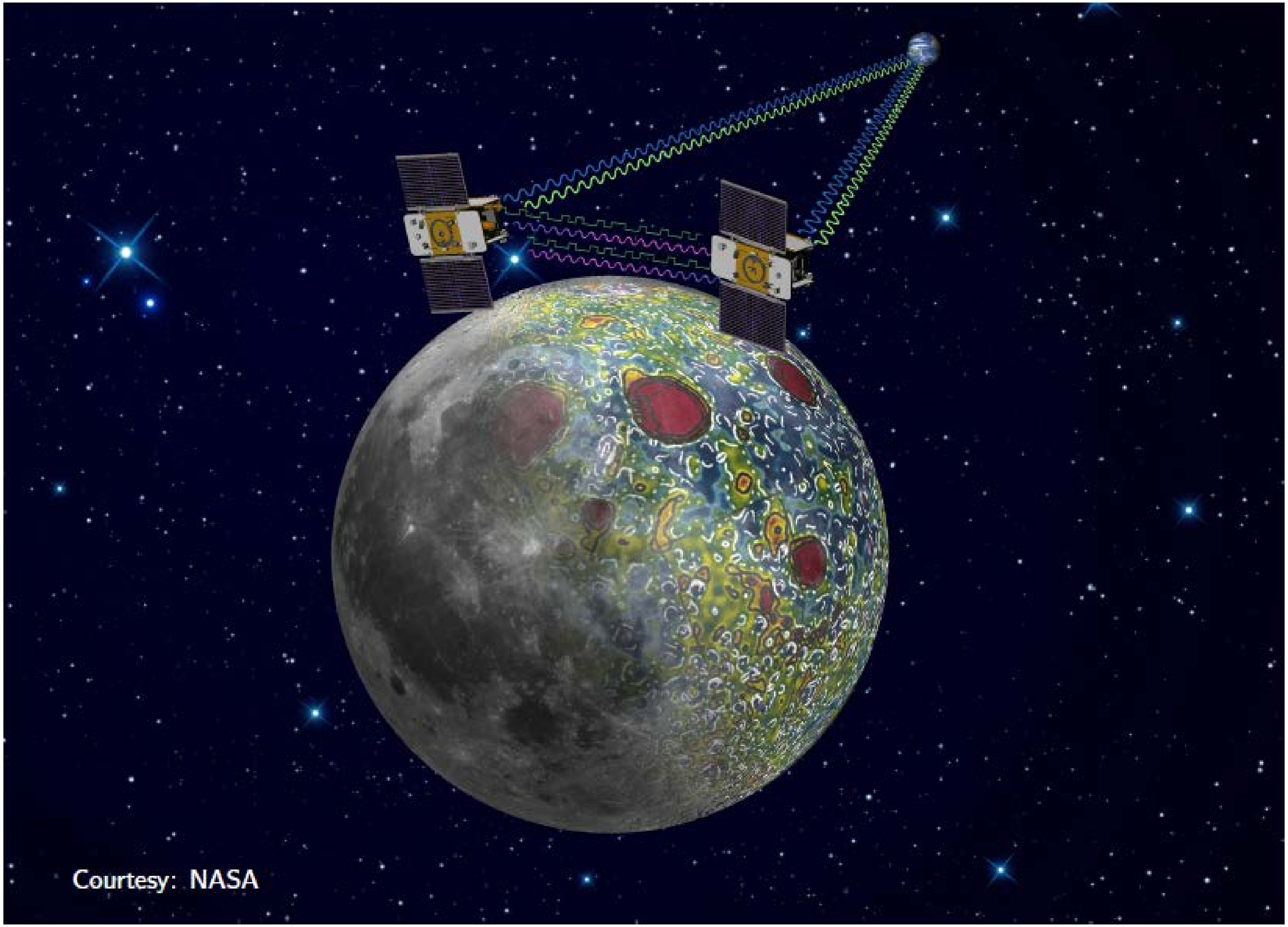
Services will be tailored to the needs of governments, scientists, decision makers, stakeholders and engineers. Special visualisation tools will be used to inform, update, and attract also the large public.

Outlook

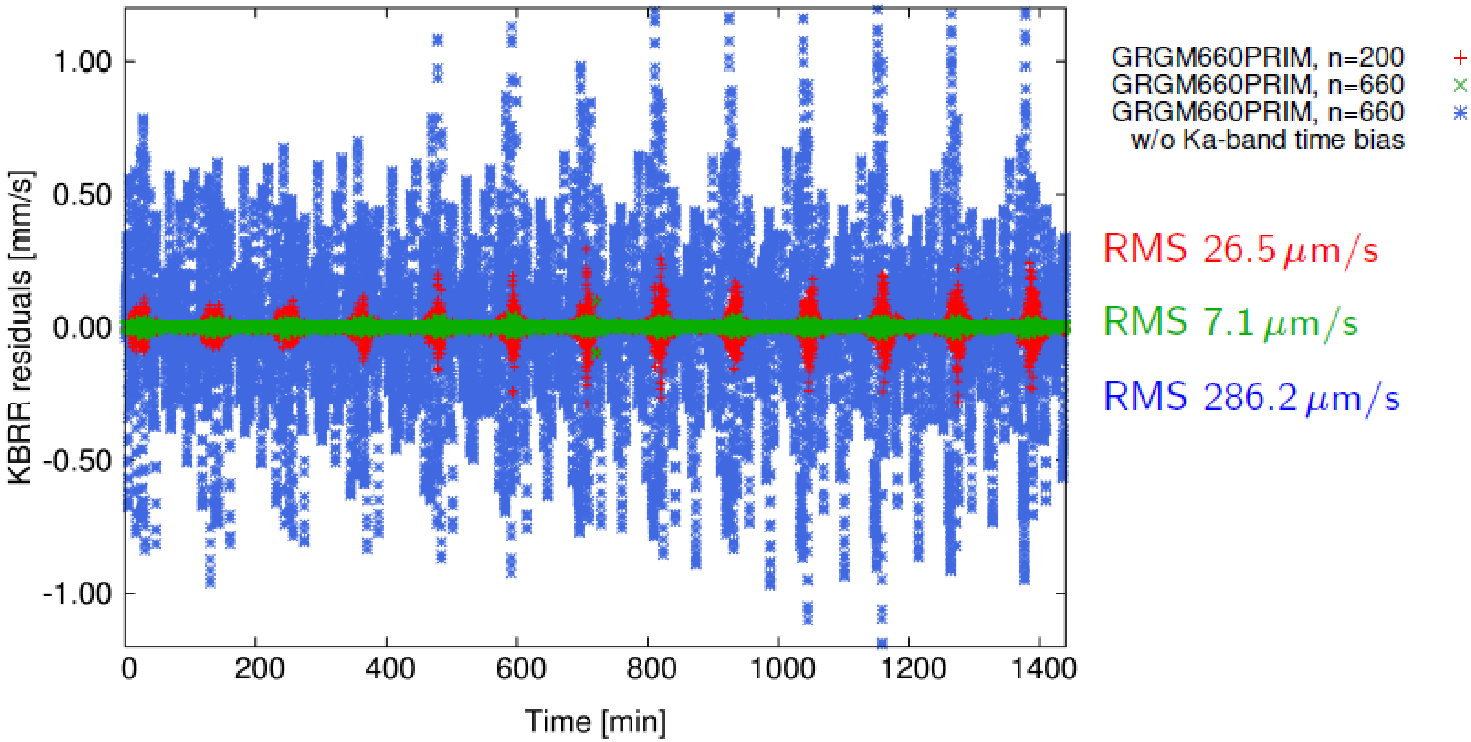
- EGSIEM will run for three years (2015–2017)
- Future integration into the services of the International Association of Geodesy (IAG), e.g., under the umbrella of the International Gravity Field Service (IGFS), and into the Copernicus emergency service is envisaged
- EGSIEM will have an open data policy and is open for collaborations with further partners.

GRAIL: Bestimmung des Schwerefeldes des Mondes

The GRAIL mission



Orbit determination: Combined

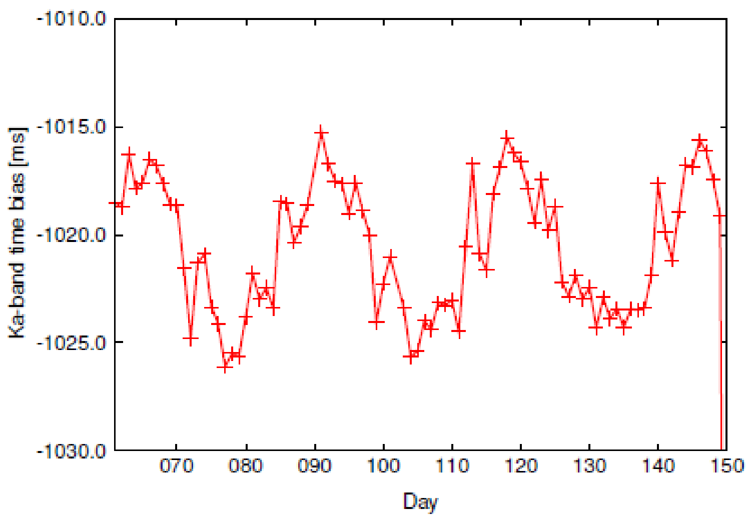


KBRR residuals (day 062) of a combined orbit determination when using release 2 data and GRGM660PRIM. Using the field to maximal degree reduces KBRR residuals, but they still show large systematic signals. Two orders of magnitude away from the expected noise level ($\sim 0.05\,\mu\mathrm{m/s}$).

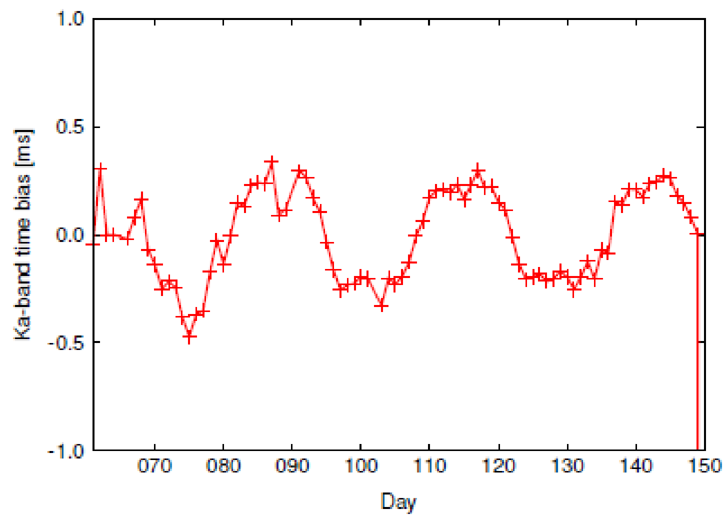
Estimation of Ka-band time bias is essential!

Ka–band time bias

Estimated Ka-band time bias for primary mission phase:



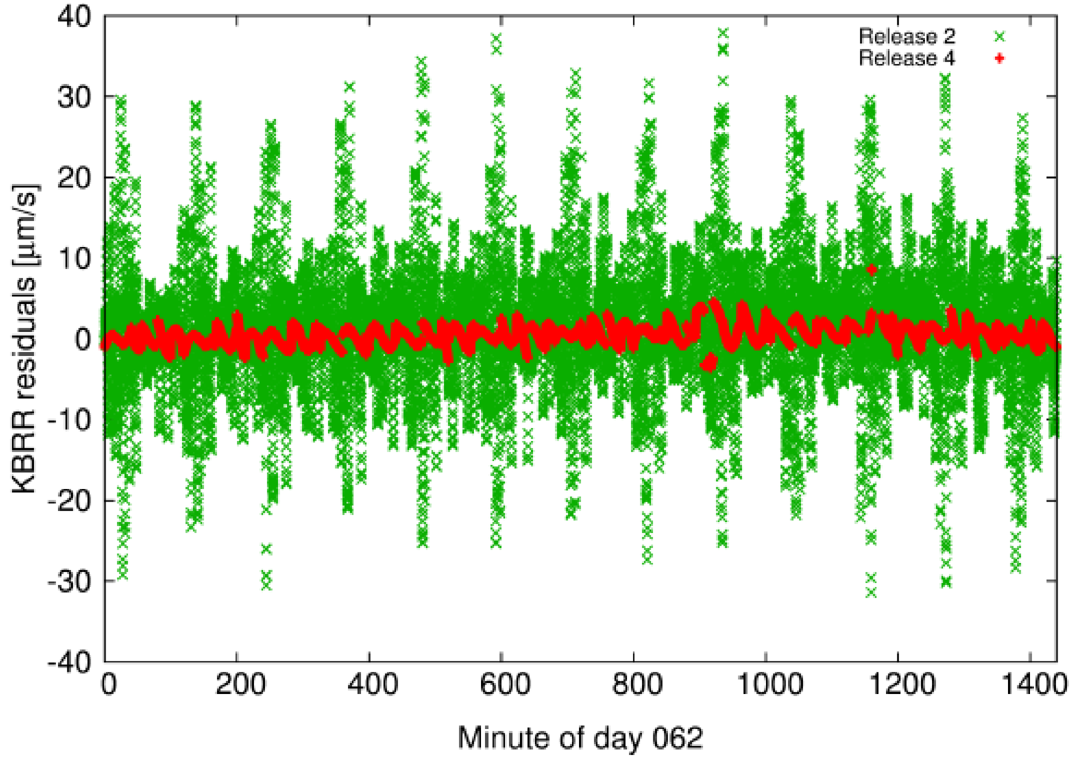
Release 2



Release 4

- Only for release 2 data of primary mission phase ($\sim -1.02\,\mathrm{s}$)
- Reason unknown
- Fixed in release 4 of data

Orbit determination: Combined, release 4

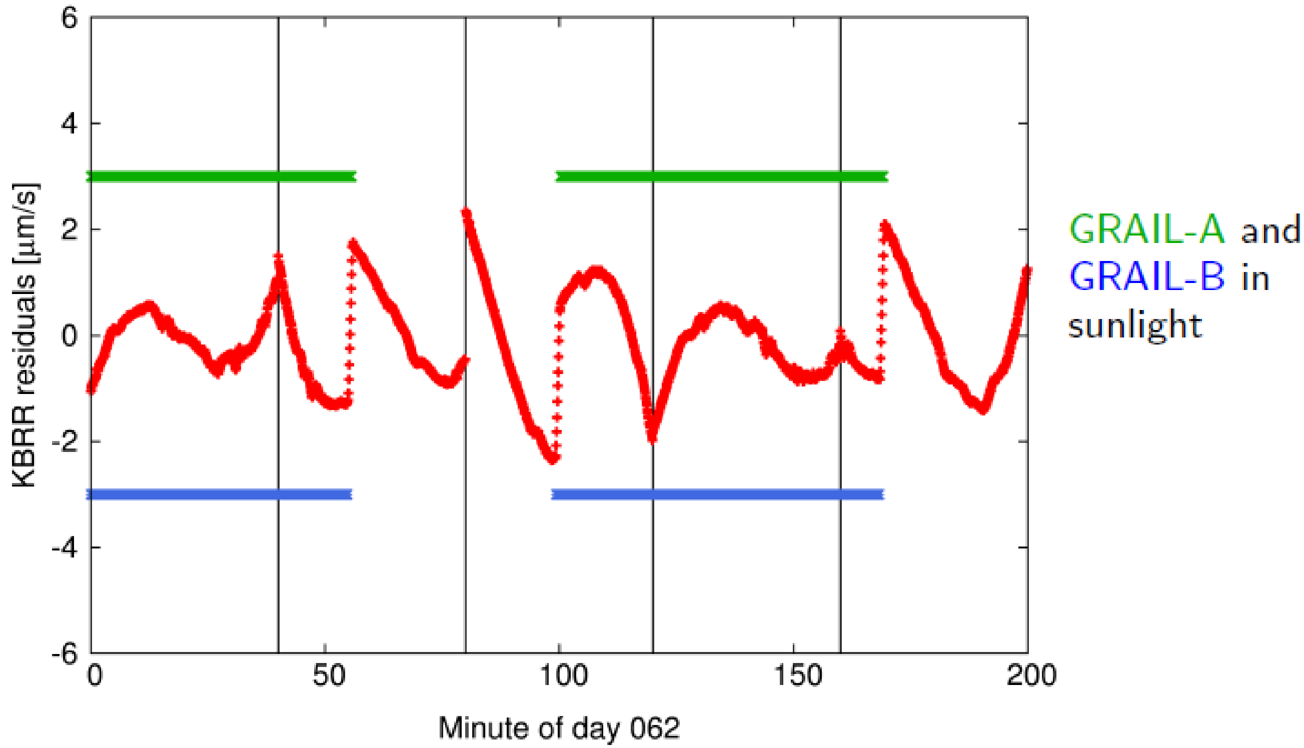


RMS 7.1 μm/s

RMS 1.3 μm/s

KBRR residuals when using release 2 data and GRGM660PRIM to $n = 660$ and release 4 data and GRGM900C to $n = 660$.

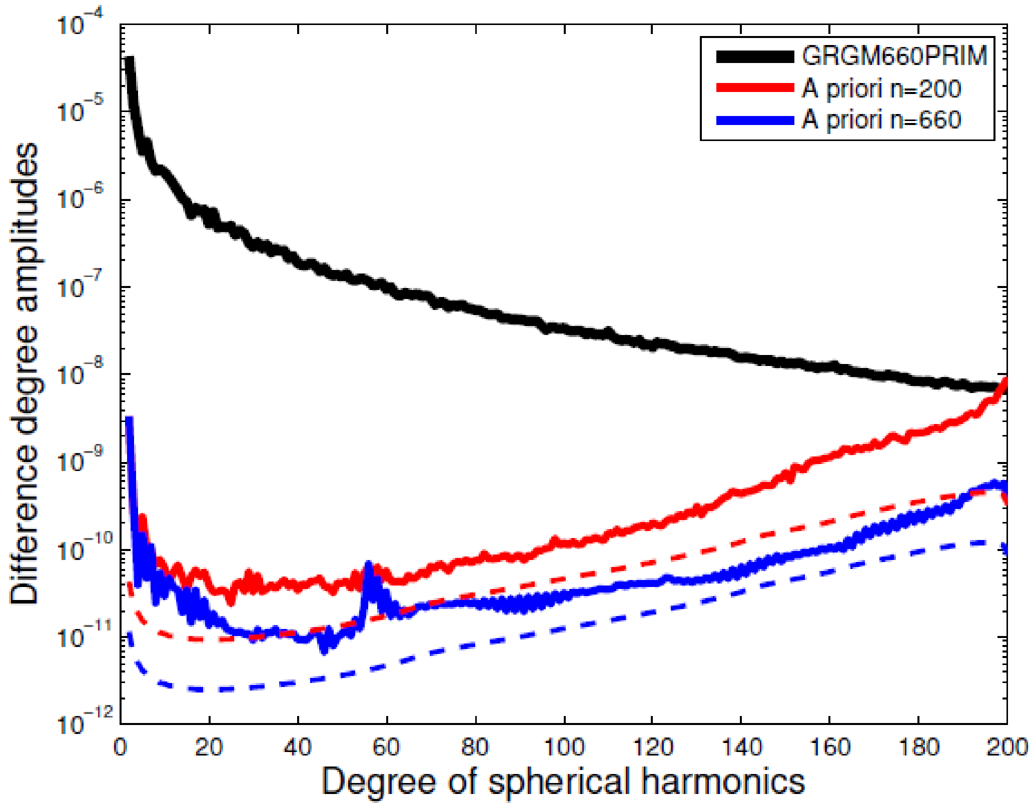
Orbit determination: Combined, release 4



The impact of the pseudo-stochstic pulses (every 40') of the currently adopted empirical orbit modeling and the solar radiation pressure becomes clearly visible.

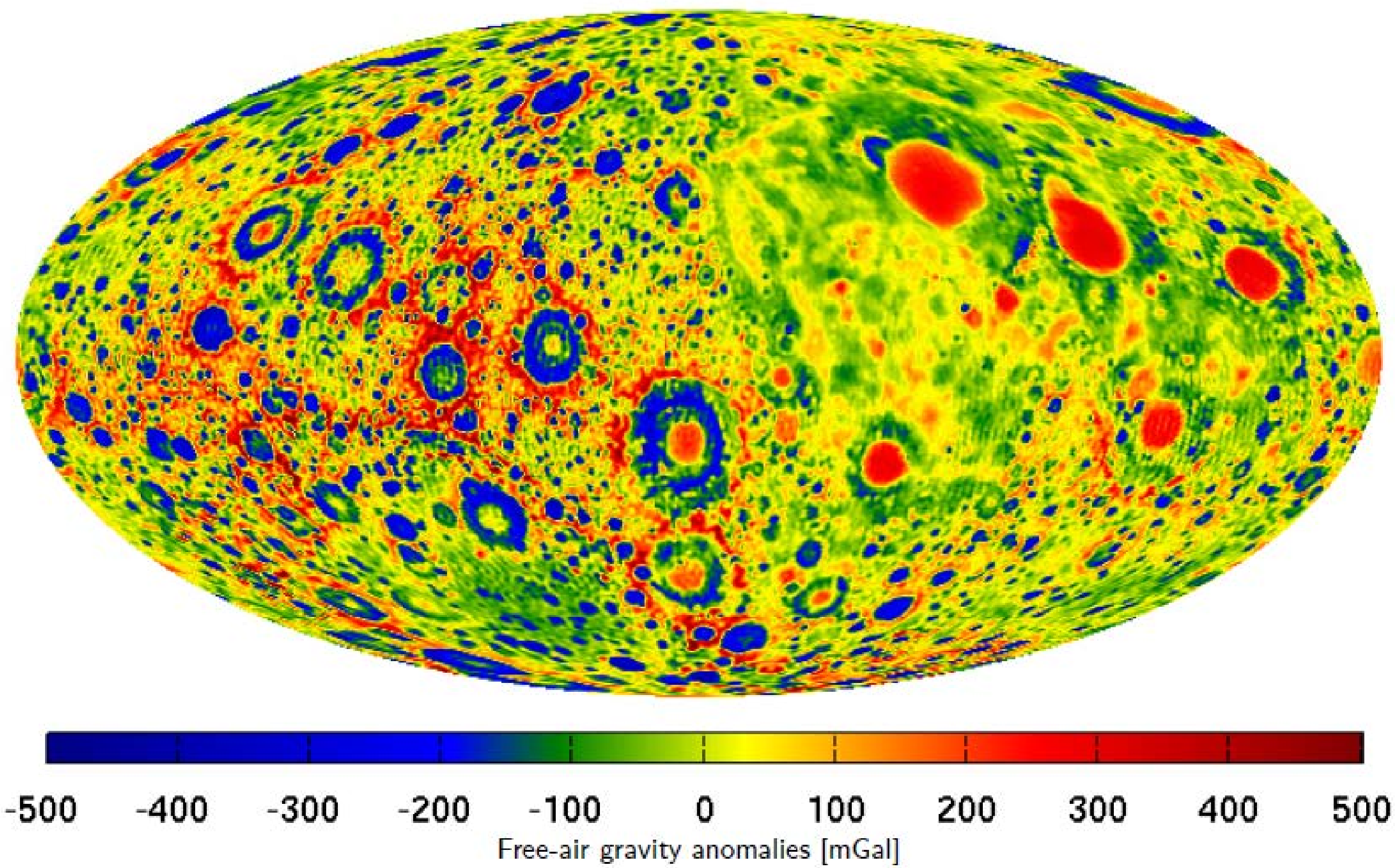
Improve force modelling to further reduce residuals!

Gravity field determination: Up to degree 200



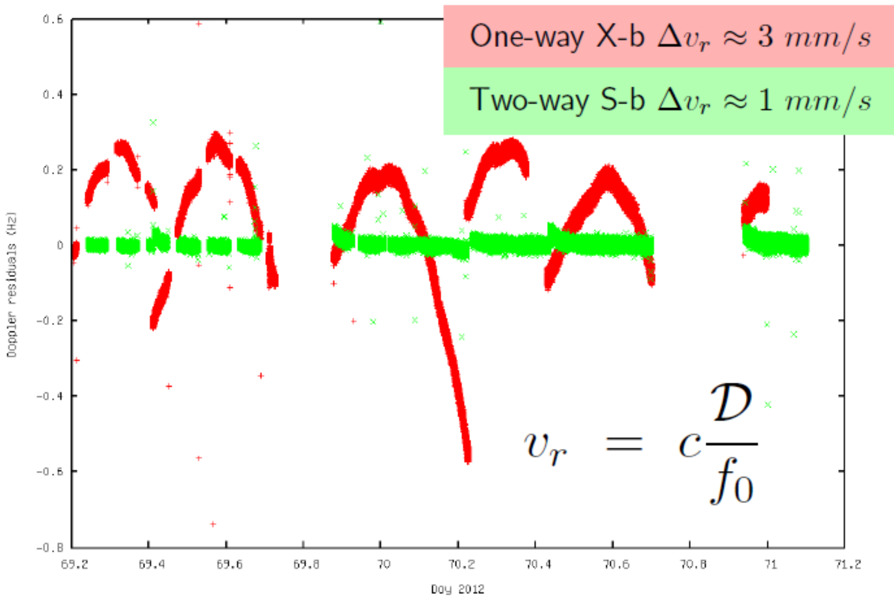
Gravity field estimated up to degree and order 200, when using GRGM660PRIM as a priori field up to $n = 200$ and $n = 660$ (to reduce omission error). No regularization is used. Position and KBRR observations are used with a relative weighting ratio of $1 : 10^8$.

Gravity field determination: Up to degree 200



A priori field to $n = 200$, grid resolution: $0.5 \times 0.5°$.

Processing of DSN data



Model based on :

- GRAIL orbit from GNI1B,
- DSN Earth-fixed coordinates,
- Earth rotation IERS2010,
- planetary ephemeris DE421.
- emitted frequency f_0:
  USO clock estimates (one-way)
  ODF station ramps (two-way)

Analytical model of one-way and two-way Doppler observations accurate at mm/s level (NASA GEODYN: 0.1 mm/s)

IN PROGRESS :

GRAIL orbit improvement based on Doppler observations in Bernese GNSS Software

Zimmerwald SLR

T. Schildknecht, P. Lauber, M. Ploner,
M. Prohaska, P. Ruzek, J. Utzinger

Astronomisches Institut

Hardware Entwicklungen

Teleskop-Steuer-PC: Lösungsmöglichkeiten wurden evaluiert. Gleichzeitig wurde ein in Hardware und Software praktisch identischer PC-Clone aufgebaut. Ein Komplettsystem-integrationstest steht kurz bevor.

Laserkopf/Doppelpass-Verstärker: Der seit letztem Jahr temporär eingesetzte Ersatzkopf ging kaputt. Es wurde ein neuer Laserkopf gebaut und installiert. Nach einer minimalen Strahlanpassung zwischen dem Lasersystem und dem Teleskop konnte der Messbetrieb rasch fortgesetzt werden. Allerdings trat gerade diese Woche erneut ein Problem mit dem Laserkopf auf.

Teleskop-Spiegel: Schwer zugängliche Spiegel wurden gereinigt. Für eine Justage wurde eruiert, welche Justagemittel wie anzuwenden sind. Verschiedene Strahlsysteme wurden diskutiert: Laser, Coudepath, Tubus sowie die dazwischenliegenden Adaptionssysteme.

Sonstiges: Optimierung der mechanischen Lage der SPAD, Austausch des Dome Antriebes.

Software Entwicklungen

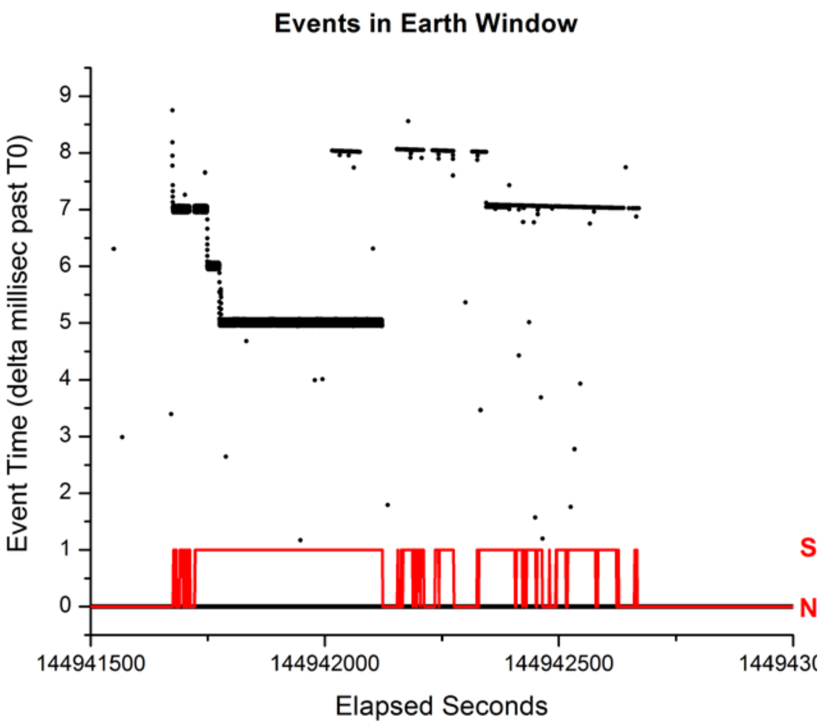
Zimlas Software: Eruierung mehrerer Ursachen für Teleskop (software)abstürze (Timeout-Bug, Problem mit Ephemeriden).

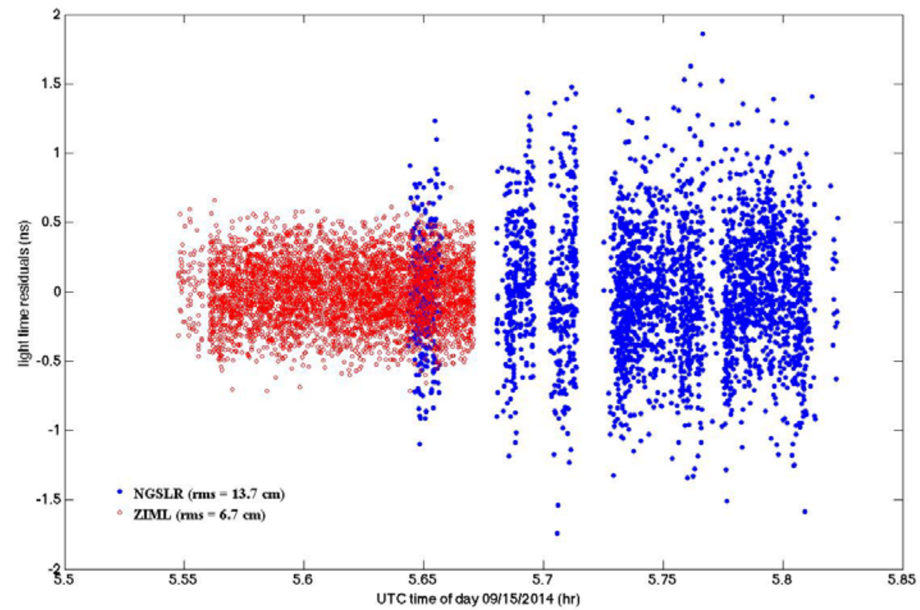
Versionskontrolle: Regelmässige Updates des Arbeitsverzeichnis, Bereinigung von Merging Konflikten, diverse Bugfixes (u.a. war in den international verschickten Normalpoint CRD-Dateien der BinRMS fehlerhaft). Reaktivierung der internen Kalibration, die für die Bestimmung der internen Kalibrationskonstanten wesentlich ist.

sCMOS-Kamera: Die Evaluierung der Tracking-Kamera wurde fortgesetzt. Die Belichtung erfolgt zwischen den Laserpulsen. Da die kameraspezifische Entwicklungssoftware nicht 100 Hz verarbeiten kann, wurde eine Realtime-Feedback Schleife zwischen Hardware und Software eingebaut, die jetzt ca. 30 Bilder pro Sekunde kontinuerlich verarbeitet.

Allsky-Bildauswertung: Stellt eine Alternative zum schlecht funktionierenden Cloud-Sensor dar. Das Allsky-Bild wird auf die spektrale Flachheit bzw. Unflachheit analysiert. Dieser Analyse geht eine Mittelung der RGB-Anteile aller Bildpixel voraus.

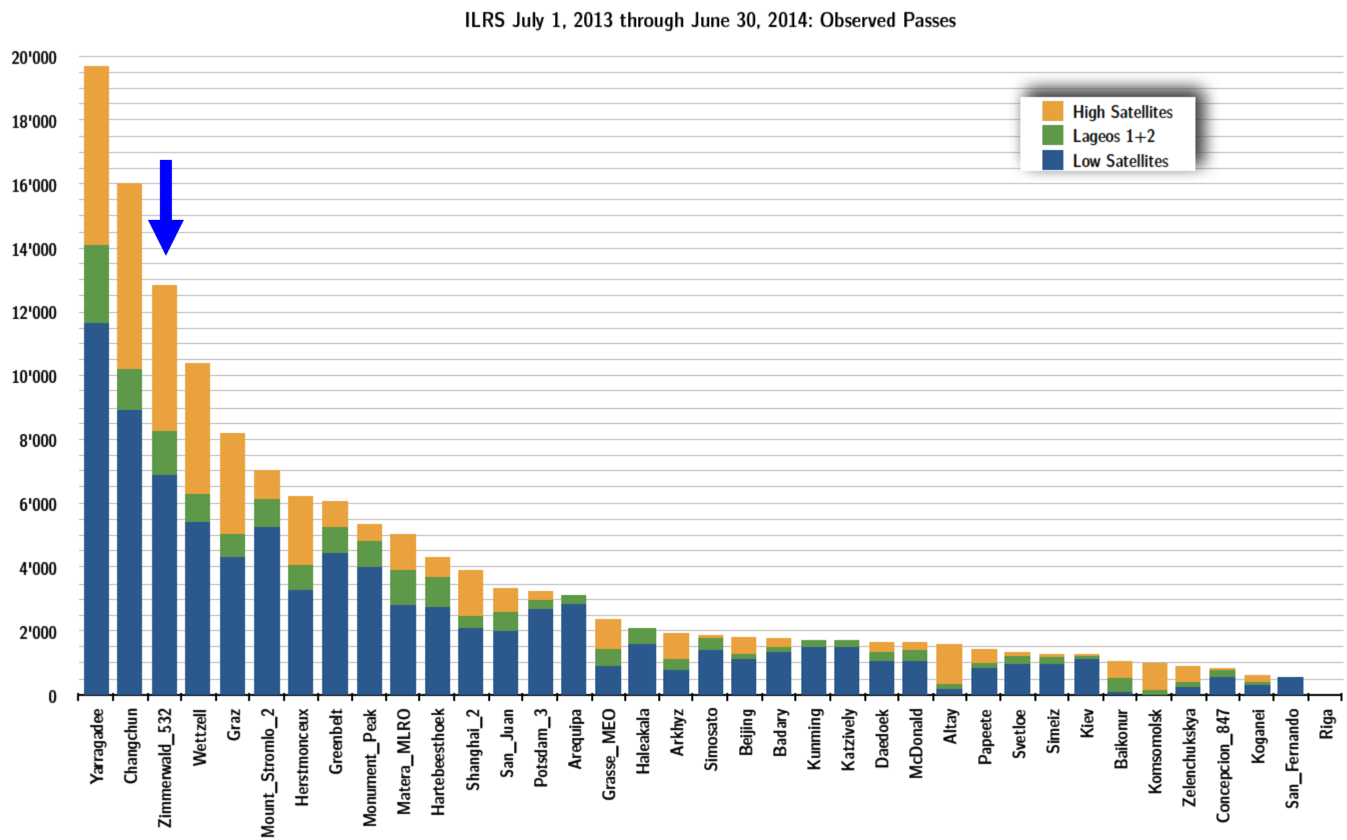
Lunar Reconnaissance Orbiter





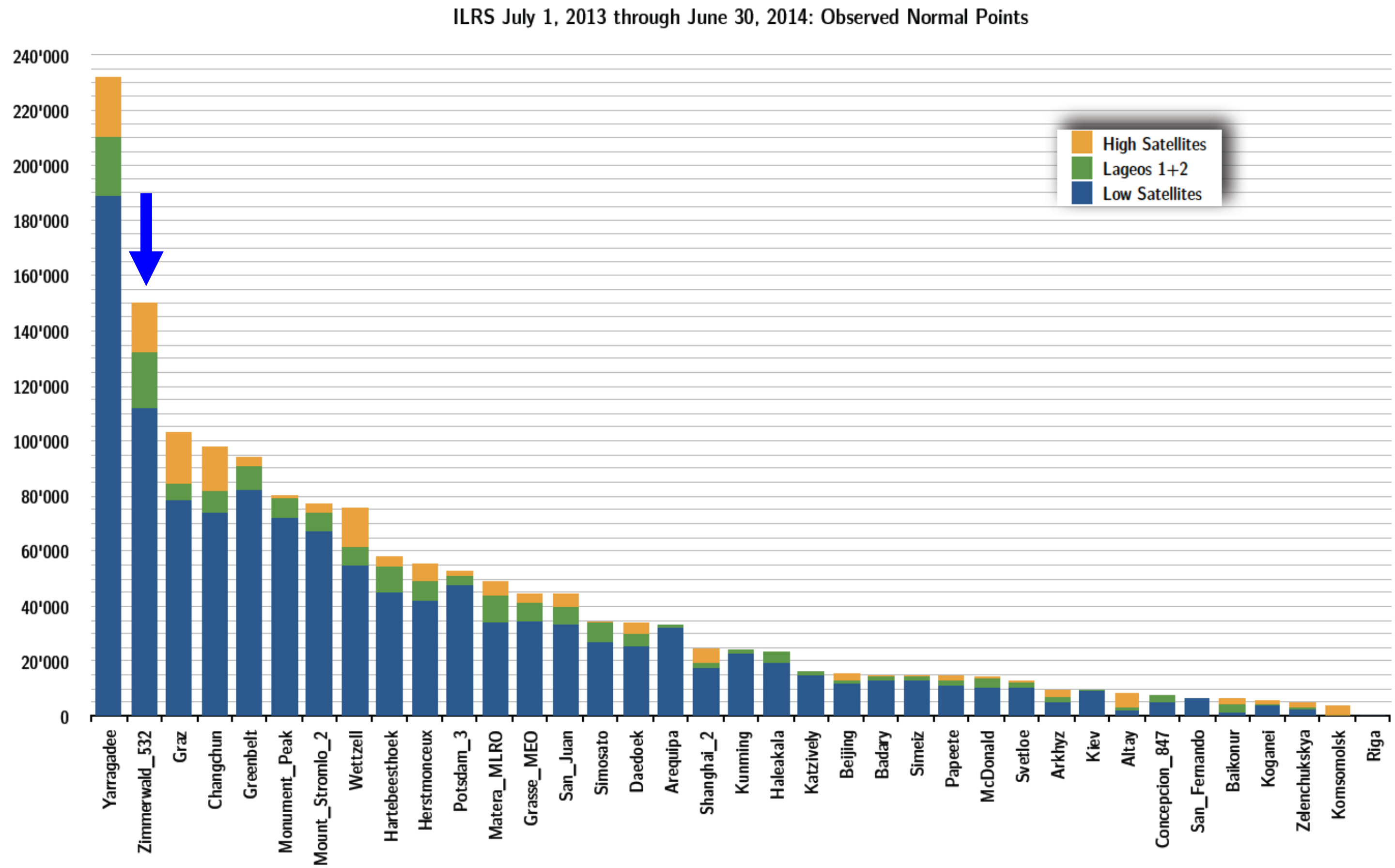
Erste Simultanmessung auf interkontinentaler Ebene zur Mondsonde. Beteiligte Stationen: Zimmerwald und Greenbelt, Maryland, USA.

Beobachtete Durchgänge



3. Rang für Zimmerwald bezüglich der Anzahl beobachteter Durchgänge (Starke Konkurrenz aus Changchun und Wettzell).

Beobachtete Normal Points



2. Rang für Zimmerwald bezüglich der Anzahl beobachteter Normalpoints (wesentlich besser als Changchun und Wettzell).

Vielen Dank für Ihre Aufmerksamkeit

Publikationen der Forschungsgruppe Satellitengeodäsie:
http://www.bernese.unibe.ch/publist